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EXERCISES IN ASTRONOMY

WHITING

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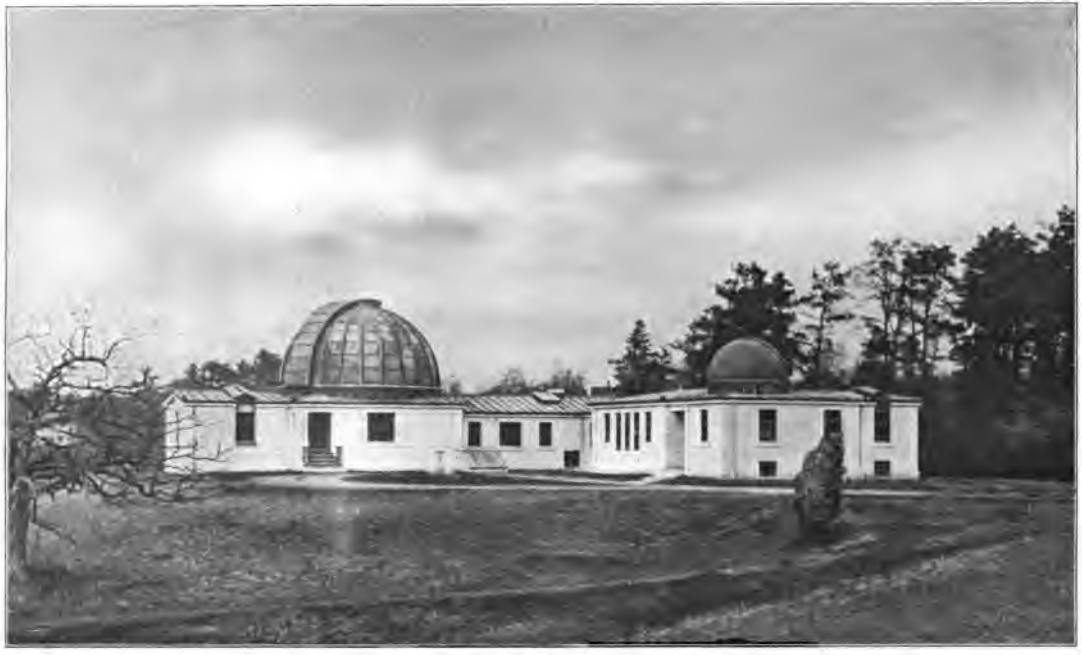

THE WHITIN OBSERVATORY OF WELLESLEY COLLEGE

Left to right: Bamberg prismatic transit, twelve-inch Clark telescope, concave grating spectroscope, libraries and computing rooms, laboratory with spectrum laboratory below, six-inch Clark telescope, small transit

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FOR SCHOOLS AND COLLEGES

BY

SARAH FRANCES WHITING, Sc.D.

WHITIN OBSERVATORY, WELLESLEY COLLEGE

GINN AND COMPANY

BOSTON · NEW YORK · CHICAGO · LONDON

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The management of schools and colleges should make the same allowance of time and money for laboratory instruction in this as in the other sciences; there should be a laboratory, a demonstrator, and fixed hours for students' daytime work. Besides the ordinary instruments of an observatory there should be collections of photographs, charts, and apparatus for the students' own handling.

The only astronomical laboratory books known to the writer are those of the South Kensington School of Science in London, and of Miss Byrd and Professor Robert Willson. These admirable handbooks outline comparatively little

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The following exercises have been proved to be practical by several years' use with classes of sixty to a hundred, handled in divisions of about fifteen, working two hours a week during the academic year.

In this work the student is, whenever possible, left to draw his own conclusions from data discussed. The American Ephemeris is in constant use, photographs of objects in the sky furnish the "specimens" for inspection, and in this subject, as in botany or zoölogy, "sharpening the pencil sharpens the eyes" — to draw the object fixes the attention upon details of structure. The graph is often used to show the relation between variables, and from it the student can often discover for himself great laws.

Moreover the intelligent person, as well as the professional astronomer, should understand the methods by which, through the daytime study of photographs of the sky taken at night, the great advances in astrophysics have been made. In this subject, as in physics, laboratory exercises can show the methods of research and prepare for it. Most plate work must be left for a second-year course, but a few sample exercises are given. The greatest modern advances in astronomy have been made by the spectroscope, and none of these can be discussed with any degree of comprehension without some laboratory work in spectrum analysis. It would be well if in the high schools simple work with the spectroscope were substituted for some of the less "juicy" experiments now included in the beginning course in physics. As it is, no knowledge of the subject can be counted on, and spectroscopes and their accessories should be provided for work in astronomy.

While this daytime work has high value, it cannot for a moment be advocated to take the place of observation in the open. All is but a means to an end, and the student should never be permitted to bend over chart or plot without fully realizing that it is a strip of the sky overhead that he is considering.

By means of daytime preparation, however, the regular program of evening observations can be greatly helped. With this, a short time out of doors, often under circumstances of more or less uncontrollable discomfort, accomplishes wonders. Directions for the record of observations with the telescope are given, with suggestions for the consultation of the Ephemeris or other publications for accurate descriptions and data.

Every student should, of course, be able to identify the constellations in the sky, and to point out objects which a field glass will reveal. The star names and the mythological figures pictured on the old maps should not be omitted, because of the allusions to them which constantly occur in both modern and classic literature. It is best not to study all the constellations at once, but to prepare for observation as they appear in succession during the academic year.

As one looks at the sky the brighter stars seem to form geometrical figures which catch the eye; within and around these the other stars can be found by alignment. It is worth while to become very familiar with these "catch figures" by sketching them on the star atlas with a pencil in the daytime; they are then quickly recognized in the sky at night. The catch figures used in these exercises are those longest in use; many of them from the old atlas of Burritt.

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In general, it is desirable to have the exercises follow as nearly as possible the plan of the lectures and recitations, but orderly arrangement does not seem possible when the objects for consideration are beyond control. Jupiter or Saturn may be visible only in the fall, when students hardly know the difference between a planet and a star; or a comet or "new star" may appear. In these cases students can obtain records of personal observation, and thus have a body of facts to work with when the topic comes up in its proper sequence.

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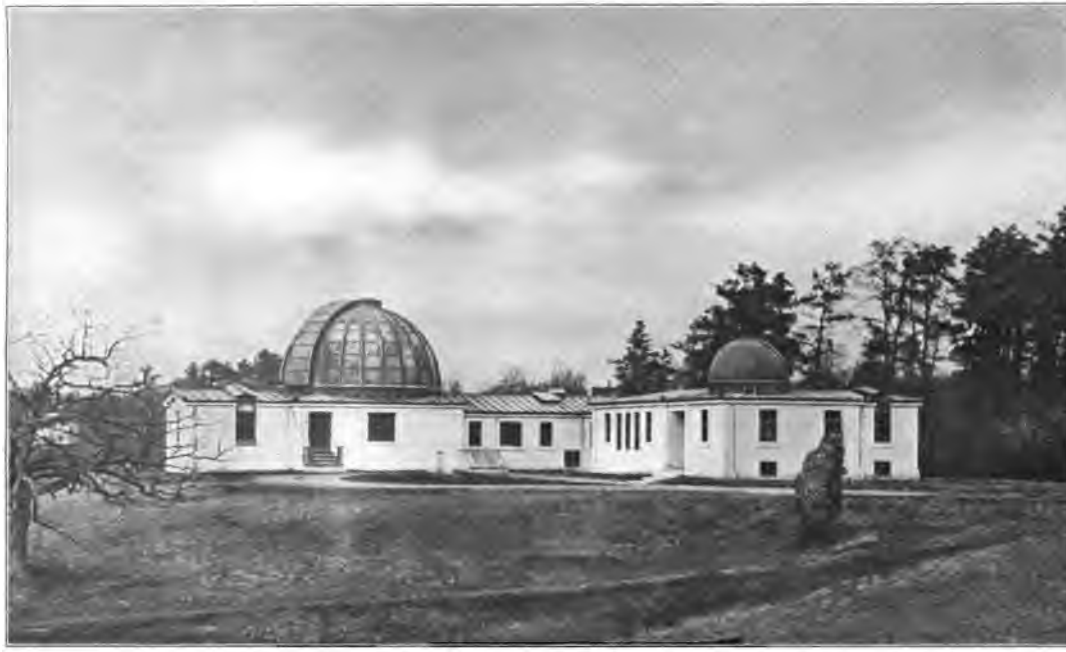

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LIBRARY OF CONGRESS

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foreign books, the charts of the southern sky through the Cordoba Observatory. Maps of the southern sky in the star atlases can be used if the larger charts are not at hand.

Frame for the illumination of lantern slides.

Screen for projecting sun spots.

These can be made by a carpenter. Sets of lantern slides may often be left for inspection on the support, and changed at intervals. For example, a set showing the complete history of Halley's comet, or famous meteorites, or any other set of pictures which it is desirable to study side by side.

II. Apparatus for Individual Work of Students

Seasonal twilight chart.

Constellation finder.

Six-inch erasable globe.

Hammett's planisphere.

Each student should be supplied with the above apparatus.

Twelve-inch celestial globe.

The solar calculator.

One globe and solar calculator will suffice for each two students.

Colas's map of the moon or the Handy Map of the Moon.

Colas's map of the moon, mounted on cloth, should be tacked to large easels, and one should be provided for each four students.

The American Ephemeris, which can be ordered from the Superintendent of Documents, Washington, D.C.

Viewing-frame for Harvard glass photographs, 8 by 10 inches.

Eyepiece for use with the glass photographs. These can be obtained of the Alvan Clark and Sons Corporation, Cambridgeport, Massachusetts.

Centimeter paper and notebook supplies.

Protractors, compasses, centimeter rulers, paper centimeter scales, etc.

The above apparatus, where not otherwise stated, can be obtained of the J. L. Hammett Company, Boston, Massachusetts. All the apparatus listed is useful and desirable, but selections can be made in beginning a student's laboratory, and additions may be provided from year to year.

LIST OF PHOTOGRAPHS AND GLASS PLATES

Selected regions of the moon: for example, Theophilus–Cyrillus–Katharina; Ptolemy–Alphons–Azachael; Clavius–Tycho; Copernicus; Mare Crisium; Mare Serenitatis; Mare Humorum; Sinus Iridum; the full moon, showing white streaks.

It would be desirable to put into the hands of each student a little booklet of half-tone pictures of different regions of the moon, but this is not yet on the market.

Sun-spot photographs in series, a set for each student.

The Pleiades, with enveloping nebulæ.

Double cluster in Perseus.

Globular cluster in Hercules.

Præsepe in Cancer, as an example of an open cluster.

N. G. C. 2682 in Cancer, as an example of a close cluster.

47 Tucanæ, the region of the Southern Cross, and other photographs of objects in the southern sky.

Messier 5 in Libra.

Two sets of photographs of Messier 5, taken at two different epochs, serve to show the variability of numerous stars in this globular cluster. A pair of these photographs should be provided for each student.

Harvard Map. This is a series of glass chart photographs of the entire sky. The following plates cover the more interesting regions: Numbers 12, 14, 18, 25, 42, 45, 50.

Spectrum plates taken at Harvard Observatory with the objective prism. Interesting plates which contain many types of stars are of the region of the Pleiades, of chi Cygni, of R Cygni, of Wolf-Rayet stars in Cygnus.

Twenty-five selected glass plates of the globular cluster omega Centauri, taken at different epochs. These plates suffice to obtain the light curve of several of the numerous variables in this cluster.

NOTE. The University of Chicago Press sends out a catalogue of photographs taken at Yerkes Observatory. Goodsell Observatory, Northfield, Minnesota, offers a list of celestial photographs. The Georgetown Observatory, Georgetown, D.C., will kindly furnish a limited number of Cestini's drawings of sun spots. The complete Atlas of the Moon, of the Paris Observatory, can be obtained through foreign book dealers. The director of Harvard Observatory shows his practical interest in laboratory astronomy by consenting to furnish plates and photographs at cost as above noted.

DIRECTIONS FOR NOTEBOOKS

1. Reserve three pages for an index, which should be kept up to date, and head successive pages as follows:

Observations with the Telescope.
Naked-eye Observations.
Laboratory Exercises.

2. Head the page of the notebook on which each new exercise is recorded with the date, the proper heading for the exercise, and the student's name.

3. Use unruled paper for drawings, horizontally ruled paper for notes, and checked centimeter paper for graphs. When tables of figures are to be recorded, rule columns vertically in pencil.

4. Make all drawings with sharp pencil; use ink for all else. A fine pen and India ink may be used to advantage in tracing graphs.

5. The notebook should in every case tell briefly and clearly what the student has seen or done; directions should not be copied.

EXERCISES IN ASTRONOMY

EXERCISE I

COÖRDINATES OF STARS FROM A STAR CATALOGUE

Object. It is of the greatest importance [illegible] with the two universal coördinates [illegible] sion and declination. To measure [illegible] *twenty* of the brightest stars will [illegible] meaning clear; moreover, the student [illegible] *names* of these stars. It happens that [illegible] globes show the places of the stars [illegible] the *middle* of the last century. [illegible] nates of the stars from a star [illegible] down to 1900, the student finds [illegible] the right ascensions [illegible]

Directions. Make six [illegible]

CONSTELLATION	STAR'S [illegible]

UNIV. OF CALIFORNIA

EXERCISES IN ASTRONOMY

EXERCISE I

COÖRDINATES OF STARS FROM GLOBE AND STAR CATALOGUE

Object. It is of the greatest importance to become familiar with the two universal coördinates of the stars, right ascension and declination. To measure these coördinates for twenty of the brightest stars will certainly make their meaning clear; moreover, the student will at once learn the names of these stars. It happens that the plates for most globes show the places of the stars given in catalogues for the middle of the last century. By looking up the coördinates of the stars from a catalogue which brings their places down to 1900, the student finds a systematic increase in all the right ascensions which he must account for.

Directions. Make six columns in your notebook as follows:

Constellation	Star Name	Globe		Catalogue	
		R.A.	Dec.	R.A.	Dec.

Write in the first two columns the following list of stars:

Above 0 Magnitude	
Alpha Canis Majoris	Sir'ius
*Alpha Argus	Canō'pus
0 Magnitude	
*Alpha Ērid'ani	Ar'chenar
Alpha Aurī'gæ	Capel'la
Beta Orionis	Rī'gel
Alpha Canis Minoris	Pro'cyon
Alpha Boö'tis	Arctū'rus
*Alpha Centau'ri	
Alpha Lȳ'ræ	Vē'ga
1st Magnitude	
Alpha Tauri	Aldeb'aran
Alpha Orionis	Bet'elguese (gerz)
Beta Geminorum	Pol'lux
Alpha Leonis	Reg'ulus
*Alpha Crucis	
Alpha Virginis	Spī'ca
*Beta Centauri	
Alpha Scorpii	Antā'res
Alpha Aq'uilæ	Altair'
Alpha Cygni	Den'eb
Alpha Piscis Austrā'lis	Fo'malhaut

Next, with a flexible scale of brass, or better, of paper, measure on the globe the right ascension and declination of each of these stars, and record in the third and fourth columns.

Finally, look up these stars in the "Catalogue of 1520 Bright Stars" from the Harvard Annals, or in the American Ephemeris, or in some catalogue which gives places for 1900.

* The five stars marked with an asterisk are invisible in intermediate northern latitudes.

Remembering that the places on the globe are for the epoch 1850, and that those of the catalogue are for 1900, record in your notebook answers to the following questions:

1. How do the right ascensions as you measure them compare with those from the catalogue?

2. In what two ways might you account for the difference?

3. Which of the two ways is more rational?

NOTE. Hipparchus discovered the precession of the equinoxes in 150 B.C.

EXERCISE II

PROBLEMS TO BE SOLVED BY GLOBES

Object. No chart can give so perfect a representation of the sky as a globe, but the globe has the disadvantage that the observer is looking at the celestial sphere from the outside instead of from the center. Solving a few problems with the globes overcomes this difficulty, and the student finds that a radius of the globe passing through the star on its surface, and extended to the celestial sphere, finds the true star.

Directions. Identify the parts of the celestial globe:

1. The artificial horizon, consisting of the amplitude circle, the azimuth circle, the points of the compass, the signs of the zodiac, the degrees of each sign, the dates of the month.

2. The celestial equator on which the right ascension is reckoned in hours from 1 to 24; the ecliptic on which the signs of the zodiac, each 30°, are marked.

3. The vernal and autumnal equinoxes; summer and winter solstices; zenith and nadir; north, south, east, and west points; the north pole and south pole.

4. The twenty-four hour circles perpendicular to the equator.

5. The brass meridian, passing through the poles of the globe, perpendicular both to the equator and the horizon. By revolving this circle the pole may be set to any elevation, so that the globe may represent the appearance of the heavens at any latitude.

6. A flexible strip graduated in degrees, which may be used to read altitudes.

Problems. 1. Set the globe to show three positions of the sphere with reference to the horizon.

a. The right sphere. Set the poles in the horizon. Note that in this position, which is found perfectly at the equator and approximately anywhere in the tropics, all the stars rise and set each day and move in circles perpendicular to the horizon.

b. The parallel sphere. Set the poles in the zenith and nadir. In this position, which is found perfectly at the poles and approximately within the polar circles, half the stars are above the horizon the whole twenty-four hours, and the other half never rise above the horizon.

c. The oblique sphere. Set the north pole at an elevation above the horizon of 45° and note that the celestial sphere is now divided into three portions: namely, all the stars within 45° of the north pole are above the horizon the whole twenty-four hours; all the stars within 45° of the south pole never rise above the horizon; all the stars of any declination between, rise and set every day.

2. Find the time of sunrise and of sunset, also the length of day at any place at any date.

Elevate the pole a number of degrees equal to the latitude of the place. Find the place of the sun on the given

date by the artificial horizon; that is, find the date and the degree and sign opposite. This is the position of the sun in the ecliptic on the day in question. Find this position on the ecliptic and bring it to the meridian. The globe now represents the appearance of the heavens at noon on the day in question. Now turn the globe until the sun is on the eastern horizon, counting the number of hour circles which pass the meridian. This shows the number of hours between sunrise and noon. Find the time of sunrise, sunset, and the length of daylight at the solstices and equinoxes at the following places: Boston, latitude 42°; London, latitude 52°; the North Cape, latitude 70°. Record the results in columns headed

PLACE	LATITUDE	DATE	SUNRISE	SUNSET	LENGTH OF DAY

3. Represent the appearance of the heavens at any time, for instance, nine o'clock on any date, at a given place.

Set the globe for the place, and find the sun's position on the ecliptic for the date, and place this under the meridian. Turn the globe west, past nine hour circles; then record what constellations are just rising east, setting west, and on the meridian. Thus study the appearance of the heavens at your station at nine o'clock on October 1, January 1, April 1, July 1.

4. Find at what date Sirius will be rising in the east as the sun sets in the west; at what date Sirius will be on the meridian at midnight. Answer the same questions for Arcturus.

EXERCISE III

STUDY OF SEASONS BY GARDNER'S SEASON APPARATUS

NOTE. Demonstrations with the apparatus referred to in this and the following exercise should be given by the instructor. Students should record in their notebooks all observations and answers to questions.

Directions. After a description of the apparatus has been given by the instructor, the globe should be separately revolved to show each point.

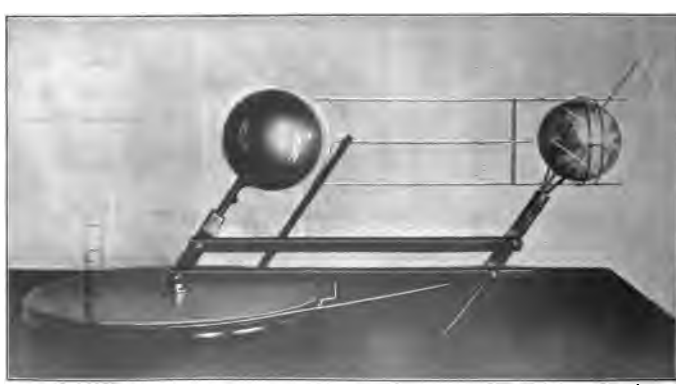

FIG. 1. GARDNER'S SEASON APPARATUS

1. Demonstration of parallelism of axis. Show that in the northern hemisphere in June the axis makes an acute angle with the perpendicular ray from the sun, in September a right angle, in December an obtuse angle, and in March a right angle again.

2. Demonstration of the relation of the circle of illumination to circles of diurnal rotation at the different seasons,

and the consequent length of day and night and amount of heat received.

3. Demonstration of the advance of the oblique ray northward in winter.

4. Demonstration of the tropics and polar circles. The slate globe and chalk may be used for this.

Answer in the notebook the following questions:

1. Towards what point in the sky does the north extremity of the earth's axis point?

2. State the angle which the axis makes with the perpendicular ray from the sun at different times of the year.

3. Define the circle of illumination and state its relation to the circles of diurnal rotation at different times of the year.

4. State when the days and nights are of equal length, and give reasons.

5. State the reason of the long polar daylight and darkness.

6. State the length of the day and of the night at the equator at different seasons.

EXERCISE IV

STUDY OF TWILIGHT BY McVICAR'S GLOBE

NOTE. If the more expensive and elaborate piece of apparatus, the McVicar's globe, is possessed, it can be used for all demonstrations of the parallelism of the axis of the earth and the seasons, but it is especially valuable to show very strikingly the varying duration of twilight from the equator to the pole.

Directions. Set the horizon twilight frame with its zenith over the place it is desired to study (directions accompany

the globe); clamp the frame and revolve the globe. It will be seen that in high latitudes the twilight belt at the summer solstice is traversed nearly all night by the sun.

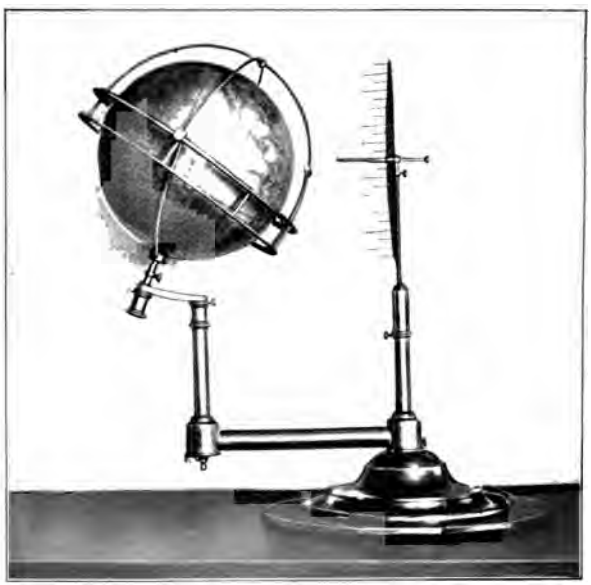

FIG. 2. MCVICAR'S GLOBE

In the same way show the shortness of twilight at the equator, on account of the perpendicular path across the twilight belt, and the duration of twilight for months at the pole.

It is especially interesting to set the twilight frame for London or Edinburgh, or places in Norway, and to note the reason for the long summer twilights so noticeable to tourists. The very short twilights in places near the equator remarked by tourists to Cuba or Panama may well be demonstrated.

EXERCISE V

STUDIES WITH THE SEASONAL TWILIGHT CHART

NOTE. This exercise consists of two parts, — drawings by the student, and studies by the use of the chart.

Before any work is attempted by the student the instructor should set up a globe and show how the chart is a projection of the celestial sphere on the meridian, from a point of observation due east in the plane of the horizon. The Sun-path Model, set sideways, shows perhaps even better what is meant by the orthographic projection in the plane of the meridian.

Material. Seasonal Twilight Chart, unruled paper, compasses, protractor, also globe and Sun-path Model.

Directions for drawings. 1. On three sheets of paper make circles fifteen centimeters in diameter. Through the center of each draw two diameters at right angles. Use the protractor to make these diameters perpendicular. Mark the horizontal diameter, which represents the horizon projected in a straight line *HO*; and the vertical one, which is the prime vertical *ZN*. With the protractor measure on the meridian, below the horizon on each side, an angle of 18°, and draw the small circle which is called " the twilight circle."

2. Complete the figure to represent the conditions in different latitudes as follows:

Measure an angle above the horizon on the north, equal to the latitude of the place, and mark it *P*. Through it and the center draw *PP*, the six-o'clock hour circle projected in a straight line.

Measure angles above the horizon on the south, and below on the north, equal to the complement of the latitude, and draw *EQ*, the equator projected in a straight line. Observe the relation *EQ* to *PP*.

Measure on the meridian, both above and below *EQ*, angles equal to the sun's declination at the solstices, namely 23°.5. Draw the diurnal path of the sun at these times. Print in small letters on these diurnal circles the dates when the sun is on them.

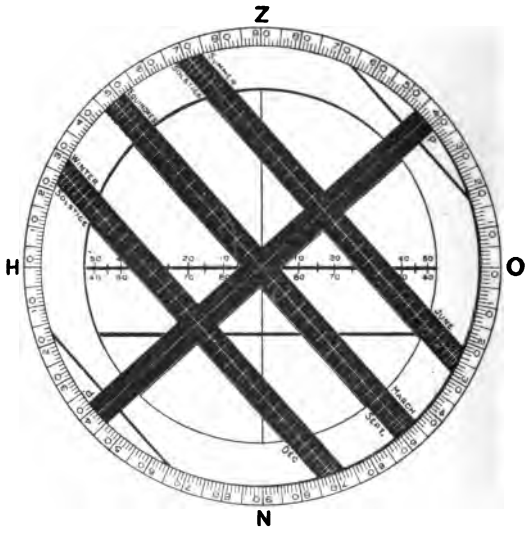

FIG. 3. SEASONAL TWILIGHT CHART

Complete projections for the following latitudes: latitude 72°, the North Cape, within the polar circle; latitude 90°, the pole; the observer's latitude.

Directions for use of chart. With the chart study the following conditions:

1. Latitude 0°, the equator. This will approximately represent conditions at Quito, Singapore, Lake Victoria Nyanza. Note that in these places the north-pole star will be in the horizon.

2. Latitude +23°.5, the northern tropic, near which are situated Havana, Sandwich Islands, Hongkong, Calcutta, Assouan.

3. Latitude 48°.5, nearly the latitude of Paris, Quebec, Vancouver.

4. Latitude 66°.5, the polar circle, near which are Archangel, Iceland, Bering Strait.

Inspect the drawings or the chart and answer the following questions:

1. In latitude 0° how are the twenty-four hours divided?

2. How does the length of day compare with the length of night?

3. How long is twilight at the equinoxes?

4. What is the noon altitude of the sun at the equinoxes? at the summer solstice? at the winter solstice?

5. In latitude 72° what is the length of day at the summer solstice? what is the midnight altitude of the sun? How are the twenty-four hours divided at the equinoxes? at the winter solstice?

6. In latitude 90° discuss the length of day, of twilight, and of night, at the summer and winter solstices and at the equinoxes.

7. What is the sun's altitude in latitude 90° at the summer solstice? How would the sun appear to move that day with reference to the horizon? What would be the form of its path as it gradually sinks to the horizon?

EXERCISES VI, VII, VIII

STUDIES OF THE MOVEMENTS OF MARS, JUPITER, AND SATURN BY MEANS OF GRAPHS

Material. The American Ephemeris, centimeter paper, pencil, centimeter ruler, colored inks, paper centimeter scales or strips cut from the centimeter paper.

Directions for plots. 1. Study the Ephemeris of the planet for the year. Note that the right ascension increases, showing that the planet is moving eastward for some months, but that at a certain date it begins to decrease, showing that the planet has begun to move west or retrograde. Mark on the margin of the Ephemeris the dates of the beginning and end of this retrograde period.

2. Head a page of the notebook "Coördinates of Planet and Ecliptic," and rule five columns.

DATE	JUPITER		ECLIPTIC	
	R.A.	DEC.	R.A.	DEC.

Take from the Ephemeris such coördinates as will place the retrogradation path of the planet in the middle of the sheet. Two dates are enough to take out for each month, except near the turning points.

3. Use a sheet of graph paper lengthwise. Graduate it to a scale in which four centimeters represent twenty minutes of right ascension and five degrees of declination.

4. With a ruler in the left hand to keep the proper right ascension, and a sharp pencil in the right to dot in

the corresponding declination, plot in the points and make through them a smooth fine line with ink. Print in small letters, beside the points, the dates at the beginning of each month.

5. Take out from the Ephemeris the coördinates for the apparent path of the sun (the ecliptic), which corresponds in hours to the path of the planet, and plot it on the graph, using red ink.

6. Take out from the Ephemeris the configurations of the planet for the year in question and record them upon the plot.

7. From the star chart find the most conspicuous stars near the planet, obtain their exact coördinates from a star catalogue, and put them on the graph.

NOTE. These plots should be held above the head toward the south, so that it may be seen that they are a representation of the apparent movements of the planets during opposition. The cause of these movements should be explained.

The above directions are general and will apply to all cases. For convenience, with a large class it is better for the instructor to take out the coördinates to be used and read them to the students, giving directions for the position of the equator on the paper, and for the range of hours in right ascension, and of degrees in declination; also the coördinates of the selected stars.

Inspect the plot just completed and answer the following questions:

1. Is the planet north or south of the ecliptic?

2. Is its latitude increasing or decreasing? Is it approaching an ascending or descending node?

3. How many days did Mars retrograde? Give the date of the middle point of retrogradation. Find the right ascension of Mars on that date, and also of the sun. State the relative positions of Mars and the sun with reference to the earth.

4. What reference stars are most convenient for watching the movements of the planet this year?

5. In what constellation must we look for the planet next year?

Answer the same questions on the graphs of Jupiter and Saturn.

EXERCISE IX

STUDY OF THE MOVEMENTS OF VENUS AS RELATED TO THE SUN — "MORNING AND EVENING STAR"

Directions. 1. Put together lengthwise three sheets of plotting paper.

2. Inspect the coördinates of Venus in the Ephemeris, and note when Venus's retrogradation loop occurs. Take out and tabulate in the notebook such coördinates as will place the loop near the left-hand side of the paper. Make also a list of the coördinates of the sun for the corresponding dates, the first and fifteenth of each month.

3. Graduate the paper to a scale in which each centimeter shall be five degrees of declination and twenty minutes of right ascension. Place the equator in the middle of the paper, and graduate on it the hours of right ascension, also graduate the degrees of declination north and south.

4. Plot in the sun's position, locating each point very distinctly by a red dot, with the date beside it in fine lettering. Connect these positions by a smooth curve in red ink. Similarly plot the path of Venus, marking its positions with black ink dots, the date beside each, and tracing its path in black ink.

5. Cut a narrow strip from the centimeter paper to use as a scale. Write in a table the measured elongation of Venus east or west of the sun for the first and fifteenth of each month.

6. Take out from the Ephemeris the "configurations" of Venus and record them upon the plot.

Questions on the graph. 1. Was Venus east or west of the sun when the plot of its path began?

2. On what date did it pass the sun and become the evening star?

3. In general, on which side of the sun is Venus when it is the evening star? when the morning star?

4. Inspect the table of elongations and state on what date is Venus at the greatest elongation.

5. Find from the table of configurations of the planet when Venus was at superior conjunction, and make a diagram showing in what part of its orbit Venus has been moving ever since.

6. Find from the Ephemeris the date when Venus will be at its greatest brilliancy. Explain.

7. Knowing that Venus shines only by reflected light, what phase does it present at superior conjunction? at inferior conjunction? at the time of greatest brilliancy?

8. Inspect the graph and state the date on which Venus passed ascending and descending node.

9. Measure on the graph the inclination of its orbit to the ecliptic.

10. At what point in its orbit does it retrograde?

The Columbia Planetarium may here be used to advantage. Remove the balls representing the moon and the superior planet, to avoid confusion, and by slowly moving the ball representing the earth show the motions of the

earth and Venus, the positions of inferior and superior conjunction, of morning and evening star.

Put on the ball representing a superior planet, and show the positions of the earth and planet at conjunction, at opposition, etc.

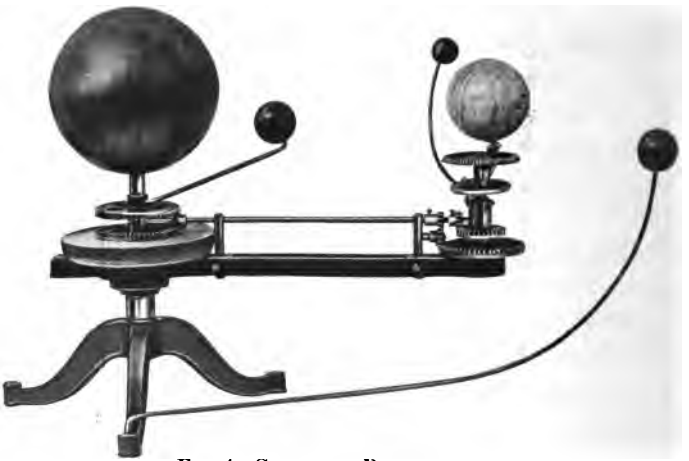

FIG. 4. COLUMBIA PLANETARIUM

EXERCISE X

STUDY OF THE MOON'S MOTIONS DURING A LUNATION

Directions. 1. Take from the Ephemeris the coördinates of the moon at noon each day for the lunation which is chosen. By the proper symbol note on your table of coördinates the time of new, half, and full moon.

2. Put together lengthwise three sheets of plotting paper. As in the Venus plot, graduate to a scale in which each centimeter shall be five degrees of declination and twenty

minutes of right ascension. Place the equator in the middle of the paper and graduate on it the hours of right ascension and also graduate degrees of declination north and south.

3. Plot the sun's path, locating each point very distinctly by a red dot, the first and fifteenth of each month, with the date beside it in fine lettering. Connect these positions by a smooth curve in red ink.

4. Plot in the moon's positions, using each time a small crescent, with its convex side turned toward the sun. Trace the path with black ink, and put in the dates of new, half, and full moon.

5. Using a strip of the paper for a measure of degrees, record in a table the number of degrees traversed each day by the moon. Also in a similar table record the number of degrees traversed by the sun.

Questions. 1. At new moon on which side of the ecliptic was the moon, and what was its latitude?

2. Give the dates at which the moon passed ascending and descending nodes.

3. From this graph show what is the approximate inclination of the moon's orbit to the ecliptic.

4. Inspect the table, giving the number of degrees through which the moon moved each day, and state in what part of the lunation it made the greatest, and also the least, daily progress. What are the names given to the moon's position in its orbit on these dates? Look at the Ephemeris and find the exact dates.

5. Beginning with new moon, on what date did the moon complete a sidereal month, or make a complete circuit in right ascension? How many days in a sidereal month? On what date did the moon complete a synodic

month, or arrive at new moon again? How many days in a synodic month?

6. How many degrees beyond a complete sidereal revolution before new moon? How far then did the sun move in its apparent orbit during this synodic month? Compute the mean distance the sun moves in twenty-nine days, and state how the distance moved this month compares with this mean. Account for this difference. (Is the sun near perihelion or aphelion?)

The Columbia Planetarium may be used to advantage to show the positions of the moon at conjunction, at opposition, etc.

EXERCISE XI

OBSERVATIONS ON THE MOON IN THE SKY

NOTE. These observations must be continued throughout the year, and record made in the notebook to be handed in after each lunation.

Directions. 1. Record the date when you first see the crescent moon in the west. Record also how many degrees north or south from the west point the crescent is seen.

2. Hold up a ruler as a horizontal line, and another ruler or pencil in line with the cusps of the moon. Note the angle which the second ruler makes with the horizontal line. Transfer this angle to the notebook each month.

Fig. 5 shows that the line joining the cusps at the vernal equinox makes an acute angle with the horizon. The figure is made for latitude 42°. Make in the notebook a figure representing the conditions in your latitude; also make a figure representing the conditions at the autumnal equinox.

Use a protractor to make these figures. Show that the old saying, that it is to be a wet or dry month according to the possibility of hanging a pail of water on the crescent, is without meaning, as the position of the crescent for any given month is invariable.

3. Note the position of the moon, with reference to the stars, when first seen, and its position each succeeding

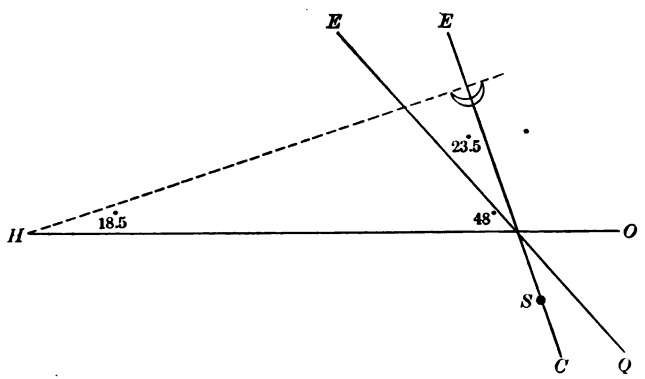

FIG. 5

night. Especially note the dates at which it passes any planets above the horizon. From these observations get a clear idea of the distance through which the moon moves eastward in a day, and of the time it takes for a complete revolution around the earth.

4. Observe during the year the meridian altitude of the full moon, and note that the full moon in winter is where the summer sun is, and that its light is therefore more brilliant than that of the summer full moon.

5. Note the position on the horizon where the full moon rises, that it is always that in which the sun rose six months before.

EXERCISE XII

STUDY OF PHOTOGRAPHS OF THE MOON

Object. To become familiar with the location and characteristics of typical regions on the moon.

Material. Colas's map of the moon (or some other good map), photographs, compasses, ruler, unruled paper.

Directions. 1. Draw a circle with a radius of seventy-five millimeters (this is the largest size convenient on the notebook paper). Draw through the center two diameters at right angles. Mark the top south, the bottom north, the right hand east, the left hand west. The map is to give the appearance of the moon in an inverting telescope. Lay off and mark distances on the horizontal diameter, from the center each way: 73, 70, 64, 57, 48, 37, 25, 12 millimeters. These are the points where the projection of the meridian for each ten degrees cuts the equatorial diameter. Draw meridians through these points and the north and south poles. This can be done fairly well on this small scale by the eye.

2. Sketch in the "seas" from the map, printing the names in small letters.

3. Study each group of photographs displayed. Locate on your skeleton map the most striking features of each region, and record in your notes the results of your study of each photograph: the place at which it was taken, the moon's age, the meridian near the terminator (from the map); whether the moon was waxing or waning; names of the principal mountains from the key; remarks concerning shadows, ridges, white streaks, or peaks which are specially luminous.

For example: Paris photograph. Moon's age, 7.8 days. Terminator, 5° east. Waxing moon. Features: Aristillus, Autolycus, Archimedes, the Apennines, Mare Serenitatis lower left, Mare Vaporum above the Apennines, Manilius left of Mare Vaporum, surrounded by luminous streaks.

4. Finally, make a list of the other photographs of the same region, stating any new features or details observed.

NOTE. Many observatories doubtless possess the superb photographs taken at the Paris Observatory. The most used of these can be backed with cloth and hung on wires about the laboratory for study. The Lick Observatory photographs also are excellent; likewise Ritchie's photographs of selected regions taken at the Yerkes Observatory.

EXERCISE XIII

A STUDY OF THE SUN-SPOT PERIOD BY WOLF'S NUMBERS

Material. A list of Wolf's numbers, loci paper, ruler, and pencil.

Explanation of Wolf's numbers from Monthly Weather Review, November, 1901. In determining the sun-spot activity, Schwabe, its discoverer, counted the spots on the surface of the sun each day, whether isolated or in groups. Wolf, of Zurich, considers the formation of a group of spots more important than the formation of a new spot in a group already existing. He uses the formula $r = 10\,g + t$; that is, the relative number of spots is equal to ten times the number of groups, plus the number of spots. If, for instance, eight spots are arranged in five groups, Wolf's number would be fifty-eight. Wolf's numbers combine the records of different observers reduced to a standard, and begin with 1749.

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LIST OF APPARATUS

I. Apparatus for Illustration

Eighteen-inch celestial globe.
Twelve-inch terrestrial globe.
Andrews's tellurion or McVicar's globe.
Gardner's season apparatus.
Columbia planetarium.
Sun-path model.
Willson's miniature equatorial and altazimuth.
Stonyhurst sun disks.
Serviss's star and planet finder.

The apparatus listed above can be obtained through the J. L. Hammett Company, Boston, Massachusetts.

Lemaire field glass, the diameter of the object glasses twenty-four ligne.
Ives's simplex normal spectroscope.
Browning's miniature direct-vision spectroscope. With this small spectroscope all observations may be taken, even to show the coincidence of the *D* line with the sodium line.
Prism spectroscope and accessories for observing the spectra of the lighter metals.
Induction coil and Plücker tubes for showing spark spectra.
Spektraltafel von Kirchhoff und Bunsen, also the colored charts of Huggins and Miller and of Vögel.
Trouvelot's Atlas of Celestial Objects (out of print, but owned by most observatories).
Durchmusterung des Nordlichen Himmels, with the accompanying text.
Uranometria Argentina (charts of the southern sky).

The field glasses, spectroscopes, and charts are furnished by many apparatus dealers, the charts of the northern sky through dealers in

foreign books, the charts of the southern sky through the Cordoba Observatory. Maps of the southern sky in the star atlases can be used if the larger charts are not at hand.

Frame for the illumination of lantern slides.

Screen for projecting sun spots.

These can be made by a carpenter. Sets of lantern slides may often be left for inspection on the support, and changed at intervals. For example, a set showing the complete history of Halley's comet, or famous meteorites, or any other set of pictures which it is desirable to study side by side.

II. Apparatus for Individual Work of Students

Seasonal twilight chart.

Constellation finder.

Six-inch erasable globe.

Hammett's planisphere.

Each student should be supplied with the above apparatus.

Twelve-inch celestial globe.

The solar calculator.

One globe and solar calculator will suffice for each two students.

Colas's map of the moon or the Handy Map of the Moon.

Colas's map of the moon, mounted on cloth, should be tacked to large easels, and one should be provided for each four students.

The American Ephemeris, which can be ordered from the Superintendent of Documents, Washington, D.C.

Viewing-frame for Harvard glass photographs, 8 by 10 inches.

Eyepiece for use with the glass photographs. These can be obtained of the Alvan Clark and Sons Corporation, Cambridgeport, Massachusetts.

Centimeter paper and notebook supplies.

Protractors, compasses, centimeter rulers, paper centimeter scales, etc.

The above apparatus, where not otherwise stated, can be obtained of the J. L. Hammett Company, Boston, Massachusetts. All the apparatus listed is useful and desirable, but selections can be made in beginning a student's laboratory, and additions may be provided from year to year.

LIST OF PHOTOGRAPHS AND GLASS PLATES

Selected regions of the moon: for example, Theophilus–Cyrillus–Katharina; Ptolemy–Alphons–Azachael; Clavius–Tycho; Copernicus; Mare Crisium; Mare Serenitatis; Mare Humorum; Sinus Iridum; the full moon, showing white streaks.

It would be desirable to put into the hands of each student a little booklet of half-tone pictures of different regions of the moon, but this is not yet on the market.

Sun-spot photographs in series, a set for each student.

The Pleiades, with enveloping nebulæ.

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Præsepe in Cancer, as an example of an open cluster.

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NOTE. The University of Chicago Press sends out a catalogue of photographs taken at Yerkes Observatory. Goodsell Observatory, Northfield, Minnesota, offers a list of celestial photographs. The Georgetown Observatory, Georgetown, D.C., will kindly furnish a limited number of Cestini's drawings of sun spots. The complete Atlas of the Moon, of the Paris Observatory, can be obtained through foreign book dealers. The director of Harvard Observatory shows his practical interest in laboratory astronomy by consenting to furnish plates and photographs at cost as above noted.

DIRECTIONS FOR NOTEBOOKS

1. Reserve three pages for an index, which should be kept up to date, and head successive pages as follows:

Observations with the Telescope.
Naked-eye Observations.
Laboratory Exercises.

2. Head the page of the notebook on which each new exercise is recorded with the date, the proper heading for the exercise, and the student's name.

3. Use unruled paper for drawings, horizontally ruled paper for notes, and checked centimeter paper for graphs. When tables of figures are to be recorded, rule columns vertically in pencil.

4. Make all drawings with sharp pencil; use ink for all else. A fine pen and India ink may be used to advantage in tracing graphs.

5. The notebook should in every case tell briefly and clearly what the student has seen or done; directions should not be copied.

UNIV. OF CALIFORNIA

EXERCISES IN ASTRONOMY

EXERCISE I

COÖRDINATES OF STARS FROM GLOBE AND STAR CATALOGUE

Object. It is of the greatest importance to become familiar with the two universal coördinates of the stars, right ascension and declination. To measure these coördinates for twenty of the brightest stars will certainly make their meaning clear; moreover, the student will at once learn the names of these stars. It happens that the plates for most globes show the places of the stars given in catalogues for the middle of the last century. By looking up the coördinates of the stars from a catalogue which brings their places down to 1900, the student finds a systematic increase in all the right ascensions which he must account for.

Directions. Make six columns in your notebook as follows:

CONSTELLATION	STAR NAME	GLOBE		CATALOGUE	
		R.A.	DEC.	R.A.	DEC.

Write in the first two columns the following list of stars:

Above 0 Magnitude	
Alpha Canis Majoris	Sir'ius
*Alpha Argus	Canō'pus
0 Magnitude	
*Alpha Ērid'ani	Ar'chenar
Alpha Aurī'gæ	Capel'la
Beta Orionis	Rī'gel
Alpha Canis Minoris	Pro'cyon
Alpha Boō'tis	Arctū'rus
*Alpha Centau'ri	
Alpha Lȳ'ræ	Vē'ga
1st Magnitude	
Alpha Tauri	Aldeb'aran
Alpha Orionis	Bet'elguese (gerz)
Beta Geminorum	Pol'lux
Alpha Leonis	Reg'ulus
*Alpha Crucis	
Alpha Virginis	Spī'ca
*Beta Centauri	
Alpha Scorpii	Antā'res
Alpha Aq'uilæ	Altair'
Alpha Cygni	Den'eb
Alpha Piscis Austrā'lis	Fo'malhaut

Next, with a flexible scale of brass, or better, of paper, measure on the globe the right ascension and declination of each of these stars, and record in the third and fourth columns.

Finally, look up these stars in the "Catalogue of 1520 Bright Stars" from the Harvard Annals, or in the American Ephemeris, or in some catalogue which gives places for 1900.

* The five stars marked with an asterisk are invisible in intermediate northern latitudes.

Remembering that the places on the globe are for the epoch 1850, and that those of the catalogue are for 1900, record in your notebook answers to the following questions:

1. How do the right ascensions as you measure them compare with those from the catalogue?

2. In what two ways might you account for the difference?

3. Which of the two ways is more rational?

NOTE. Hipparchus discovered the precession of the equinoxes in 150 B.C.

EXERCISE II

PROBLEMS TO BE SOLVED BY GLOBES

Object. No chart can give so perfect a representation of the sky as a globe, but the globe has the disadvantage that the observer is looking at the celestial sphere from the outside instead of from the center. Solving a few problems with the globes overcomes this difficulty, and the student finds that a radius of the globe passing through the star on its surface, and extended to the celestial sphere, finds the true star.

Directions. Identify the parts of the celestial globe:

1. The artificial horizon, consisting of the amplitude circle, the azimuth circle, the points of the compass, the signs of the zodiac, the degrees of each sign, the dates of the month.

2. The celestial equator on which the right ascension is reckoned in hours from 1 to 24; the ecliptic on which the signs of the zodiac, each 30°, are marked.

3. The vernal and autumnal equinoxes; summer and winter solstices; zenith and nadir; north, south, east, and west points; the north pole and south pole.

4. The twenty-four hour circles perpendicular to the equator.

5. The brass meridian, passing through the poles of the globe, perpendicular both to the equator and the horizon. By revolving this circle the pole may be set to any elevation, so that the globe may represent the appearance of the heavens at any latitude.

6. A flexible strip graduated in degrees, which may be used to read altitudes.

Problems. 1. Set the globe to show three positions of the sphere with reference to the horizon.

a. The right sphere. Set the poles in the horizon. Note that in this position, which is found perfectly at the equator and approximately anywhere in the tropics, all the stars rise and set each day and move in circles perpendicular to the horizon.

b. The parallel sphere. Set the poles in the zenith and nadir. In this position, which is found perfectly at the poles and approximately within the polar circles, half the stars are above the horizon the whole twenty-four hours, and the other half never rise above the horizon.

c. The oblique sphere. Set the north pole at an elevation above the horizon of 45° and note that the celestial sphere is now divided into three portions: namely, all the stars within 45° of the north pole are above the horizon the whole twenty-four hours; all the stars within 45° of the south pole never rise above the horizon; all the stars of any declination between, rise and set every day.

2. Find the time of sunrise and of sunset, also the length of day at any place at any date.

Elevate the pole a number of degrees equal to the latitude of the place. Find the place of the sun on the given

date by the artificial horizon; that is, find the date and the degree and sign opposite. This is the position of the sun in the ecliptic on the day in question. Find this position on the ecliptic and bring it to the meridian. The globe now represents the appearance of the heavens at noon on the day in question. Now turn the globe until the sun is on the eastern horizon, counting the number of hour circles which pass the meridian. This shows the number of hours between sunrise and noon. Find the time of sunrise, sunset, and the length of daylight at the solstices and equinoxes at the following places: Boston, latitude 42°; London, latitude 52°; the North Cape, latitude 70°. Record the results in columns headed

PLACE	LATITUDE	DATE	SUNRISE	SUNSET	LENGTH OF DAY

3. Represent the appearance of the heavens at any time, for instance, nine o'clock on any date, at a given place.

Set the globe for the place, and find the sun's position on the ecliptic for the date, and place this under the meridian. Turn the globe west, past nine hour circles; then record what constellations are just rising east, setting west, and on the meridian. Thus study the appearance of the heavens at your station at nine o'clock on October 1, January 1, April 1, July 1.

4. Find at what date Sirius will be rising in the east as the sun sets in the west; at what date Sirius will be on the meridian at midnight. Answer the same questions for Arcturus.

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EXERCISE I

COÖRDINATES OF STARS FROM GLOBE AND STAR CATALOGUE

Object. It is of the greatest importance to become familiar with the two universal coördinates of the stars, right ascension and declination. To measure these coördinates for twenty of the brightest stars will certainly make their meaning clear; moreover, the student will at once learn the names of these stars. It happens that the plates for most globes show the places of the stars given in catalogues for the middle of the last century. By looking up the coördinates of the stars from a catalogue which brings their places down to 1900, the student finds a systematic increase in all the right ascensions which he must account for.

Directions. Make six columns in your notebook as follows:

CONSTELLATION	STAR NAME	GLOBE		CATALOGUE	
		R.A.	DEC.	R.A.	DEC.

Write in the first two columns the following list of stars:

Above 0 Magnitude	
Alpha Canis Majoris	Sir'ius
*Alpha Argus	Canō'pus
0 Magnitude	
*Alpha Ērid'ani	Ar'chenar
Alpha Aurī'gæ	Capel'la
Beta Orionis	Rī'gel
Alpha Canis Minoris	Pro'cyon
Alpha Boö'tis	Arctū'rus
*Alpha Centau'ri	
Alpha Lȳ'ræ	Vē'ga
1st Magnitude	
Alpha Tauri	Aldeb'aran
Alpha Orionis	Bet'elguese (gerz)
Beta Geminorum	Pol'lux
Alpha Leonis	Reg'ulus
*Alpha Crucis	
Alpha Virginis	Spī'ca
*Beta Centauri	
Alpha Scorpii	Antā'res
Alpha Aq'uilæ	Altair'
Alpha Cygni	Den'eb
Alpha Piscis Austrā'lis	Fo'malhaut

Next, with a flexible scale of brass, or better, of paper, measure on the globe the right ascension and declination of each of these stars, and record in the third and fourth columns.

Finally, look up these stars in the "Catalogue of 1520 Bright Stars" from the Harvard Annals, or in the American Ephemeris, or in some catalogue which gives places for 1900.

* The five stars marked with an asterisk are invisible in intermediate northern latitudes.

Remembering that the places on the globe are for the epoch 1850, and that those of the catalogue are for 1900, record in your notebook answers to the following questions:

1. How do the right ascensions as you measure them compare with those from the catalogue?

2. In what two ways might you account for the difference?

3. Which of the two ways is more rational?

NOTE. Hipparchus discovered the precession of the equinoxes in 150 B.C.

EXERCISE II

PROBLEMS TO BE SOLVED BY GLOBES

Object. No chart can give so perfect a representation of the sky as a globe, but the globe has the disadvantage that the observer is looking at the celestial sphere from the outside instead of from the center. Solving a few problems with the globes overcomes this difficulty, and the student finds that a radius of the globe passing through the star on its surface, and extended to the celestial sphere, finds the true star.

Directions. Identify the parts of the celestial globe:

1. The artificial horizon, consisting of the amplitude circle, the azimuth circle, the points of the compass, the signs of the zodiac, the degrees of each sign, the dates of the month.

2. The celestial equator on which the right ascension is reckoned in hours from 1 to 24; the ecliptic on which the signs of the zodiac, each 30°, are marked.

3. The vernal and autumnal equinoxes; summer and winter solstices; zenith and nadir; north, south, east, and west points; the north pole and south pole.

4. The twenty-four hour circles perpendicular to the equator.

5. The brass meridian, passing through the poles of the globe, perpendicular both to the equator and the horizon. By revolving this circle the pole may be set to any elevation, so that the globe may represent the appearance of the heavens at any latitude.

6. A flexible strip graduated in degrees, which may be used to read altitudes.

Problems. 1. Set the globe to show three positions of the sphere with reference to the horizon.

a. The right sphere. Set the poles in the horizon. Note that in this position, which is found perfectly at the equator and approximately anywhere in the tropics, all the stars rise and set each day and move in circles perpendicular to the horizon.

b. The parallel sphere. Set the poles in the zenith and nadir. In this position, which is found perfectly at the poles and approximately within the polar circles, half the stars are above the horizon the whole twenty-four hours, and the other half never rise above the horizon.

c. The oblique sphere. Set the north pole at an elevation above the horizon of 45° and note that the celestial sphere is now divided into three portions: namely, all the stars within 45° of the north pole are above the horizon the whole twenty-four hours; all the stars within 45° of the south pole never rise above the horizon; all the stars of any declination between, rise and set every day.

2. Find the time of sunrise and of sunset, also the length of day at any place at any date.

Elevate the pole a number of degrees equal to the latitude of the place. Find the place of the sun on the given

date by the artificial horizon; that is, find the date and the degree and sign opposite. This is the position of the sun in the ecliptic on the day in question. Find this position on the ecliptic and bring it to the meridian. The globe now represents the appearance of the heavens at noon on the day in question. Now turn the globe until the sun is on the eastern horizon, counting the number of hour circles which pass the meridian. This shows the number of hours between sunrise and noon. Find the time of sunrise, sunset, and the length of daylight at the solstices and equinoxes at the following places: Boston, latitude 42°; London, latitude 52°; the North Cape, latitude 70°. Record the results in columns headed

PLACE	LATITUDE	DATE	SUNRISE	SUNSET	LENGTH OF DAY

3. Represent the appearance of the heavens at any time, for instance, nine o'clock on any date, at a given place.

Set the globe for the place, and find the sun's position on the ecliptic for the date, and place this under the meridian. Turn the globe west, past nine hour circles; then record what constellations are just rising east, setting west, and on the meridian. Thus study the appearance of the heavens at your station at nine o'clock on October 1, January 1, April 1, July 1.

4. Find at what date Sirius will be rising in the east as the sun sets in the west; at what date Sirius will be on the meridian at midnight. Answer the same questions for Arcturus.

EXERCISE III

STUDY OF SEASONS BY GARDNER'S SEASON APPARATUS

NOTE. Demonstrations with the apparatus referred to in this and the following exercise should be given by the instructor. Students should record in their notebooks all observations and answers to questions.

Directions. After a description of the apparatus has been given by the instructor, the globe should be separately revolved to show each point.

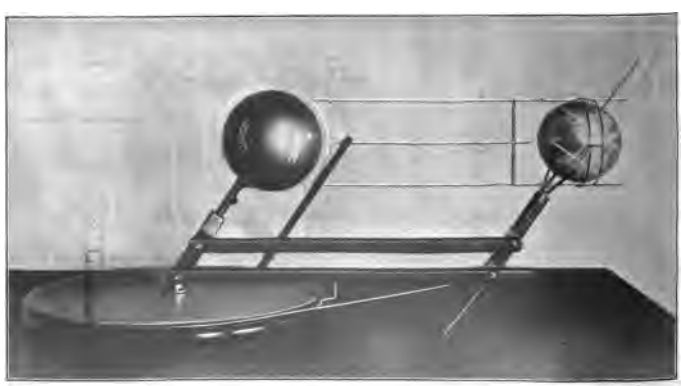

FIG. 1. GARDNER'S SEASON APPARATUS

1. Demonstration of parallelism of axis. Show that in the northern hemisphere in June the axis makes an acute angle with the perpendicular ray from the sun, in September a right angle, in December an obtuse angle, and in March a right angle again.

2. Demonstration of the relation of the circle of illumination to circles of diurnal rotation at the different seasons,

and the consequent length of day and night and amount of heat received.

3. Demonstration of the advance of the oblique ray northward in winter.

4. Demonstration of the tropics and polar circles. The slate globe and chalk may be used for this.

Answer in the notebook the following questions:

1. Towards what point in the sky does the north extremity of the earth's axis point?

2. State the angle which the axis makes with the perpendicular ray from the sun at different times of the year.

3. Define the circle of illumination and state its relation to the circles of diurnal rotation at different times of the year.

4. State when the days and nights are of equal length, and give reasons.

5. State the reason of the long polar daylight and darkness.

6. State the length of the day and of the night at the equator at different seasons.

EXERCISE IV

STUDY OF TWILIGHT BY McVICAR'S GLOBE

NOTE. If the more expensive and elaborate piece of apparatus, the McVicar's globe, is possessed, it can be used for all demonstrations of the parallelism of the axis of the earth and the seasons, but it is especially valuable to show very strikingly the varying duration of twilight from the equator to the pole.

Directions. Set the horizon twilight frame with its zenith over the place it is desired to study (directions accompany

the globe); clamp the frame and revolve the globe. It will be seen that in high latitudes the twilight belt at the summer solstice is traversed nearly all night by the sun.

FIG. 2. MCVICAR'S GLOBE

In the same way show the shortness of twilight at the equator, on account of the perpendicular path across the twilight belt, and the duration of twilight for months at the pole.

It is especially interesting to set the twilight frame for London or Edinburgh, or places in Norway, and to note the reason for the long summer twilights so noticeable to tourists. The very short twilights in places near the equator remarked by tourists to Cuba or Panama may well be demonstrated.

EXERCISE V

STUDIES WITH THE SEASONAL TWILIGHT CHART

NOTE. This exercise consists of two parts, — drawings by the student, and studies by the use of the chart.

Before any work is attempted by the student the instructor should set up a globe and show how the chart is a projection of the celestial sphere on the meridian, from a point of observation due east in the plane of the horizon. The Sun-path Model, set sideways, shows perhaps even better what is meant by the orthographic projection in the plane of the meridian.

Material. Seasonal Twilight Chart, unruled paper, compasses, protractor, also globe and Sun-path Model.

Directions for drawings. 1. On three sheets of paper make circles fifteen centimeters in diameter. Through the center of each draw two diameters at right angles. Use the protractor to make these diameters perpendicular. Mark the horizontal diameter, which represents the horizon projected in a straight line HO; and the vertical one, which is the prime vertical ZN. With the protractor measure on the meridian, below the horizon on each side, an angle of 18°, and draw the small circle which is called " the twilight circle."

2. Complete the figure to represent the conditions in different latitudes as follows:

Measure an angle above the horizon on the north, equal to the latitude of the place, and mark it P. Through it and the center draw PP, the six-o'clock hour circle projected in a straight line.

Measure angles above the horizon on the south, and below on the north, equal to the complement of the latitude, and draw EQ, the equator projected in a straight line. Observe the relation EQ to PP.

NOTE. The University of Chicago Press sends out a catalogue of photographs taken at Yerkes Observatory. Goodsell Observatory, Northfield, Minnesota, offers a list of celestial photographs. The Georgetown Observatory, Georgetown, D.C., will kindly furnish a limited number of Cestini's drawings of sun spots. The complete Atlas of the Moon, of the Paris Observatory, can be obtained through foreign book dealers. The director of Harvard Observatory shows his practical interest in laboratory astronomy by consenting to furnish plates and photographs at cost as above noted.

DIRECTIONS FOR NOTEBOOKS

1. Reserve three pages for an index, which should be kept up to date, and head successive pages as follows:

Observations with the Telescope.
Naked-eye Observations.
Laboratory Exercises.

2. Head the page of the notebook on which each new exercise is recorded with the date, the proper heading for the exercise, and the student's name.

3. Use unruled paper for drawings, horizontally ruled paper for notes, and checked centimeter paper for graphs. When tables of figures are to be recorded, rule columns vertically in pencil.

4. Make all drawings with sharp pencil; use ink for all else. A fine pen and India ink may be used to advantage in tracing graphs.

5. The notebook should in every case tell briefly and clearly what the student has seen or done; directions should not be copied.

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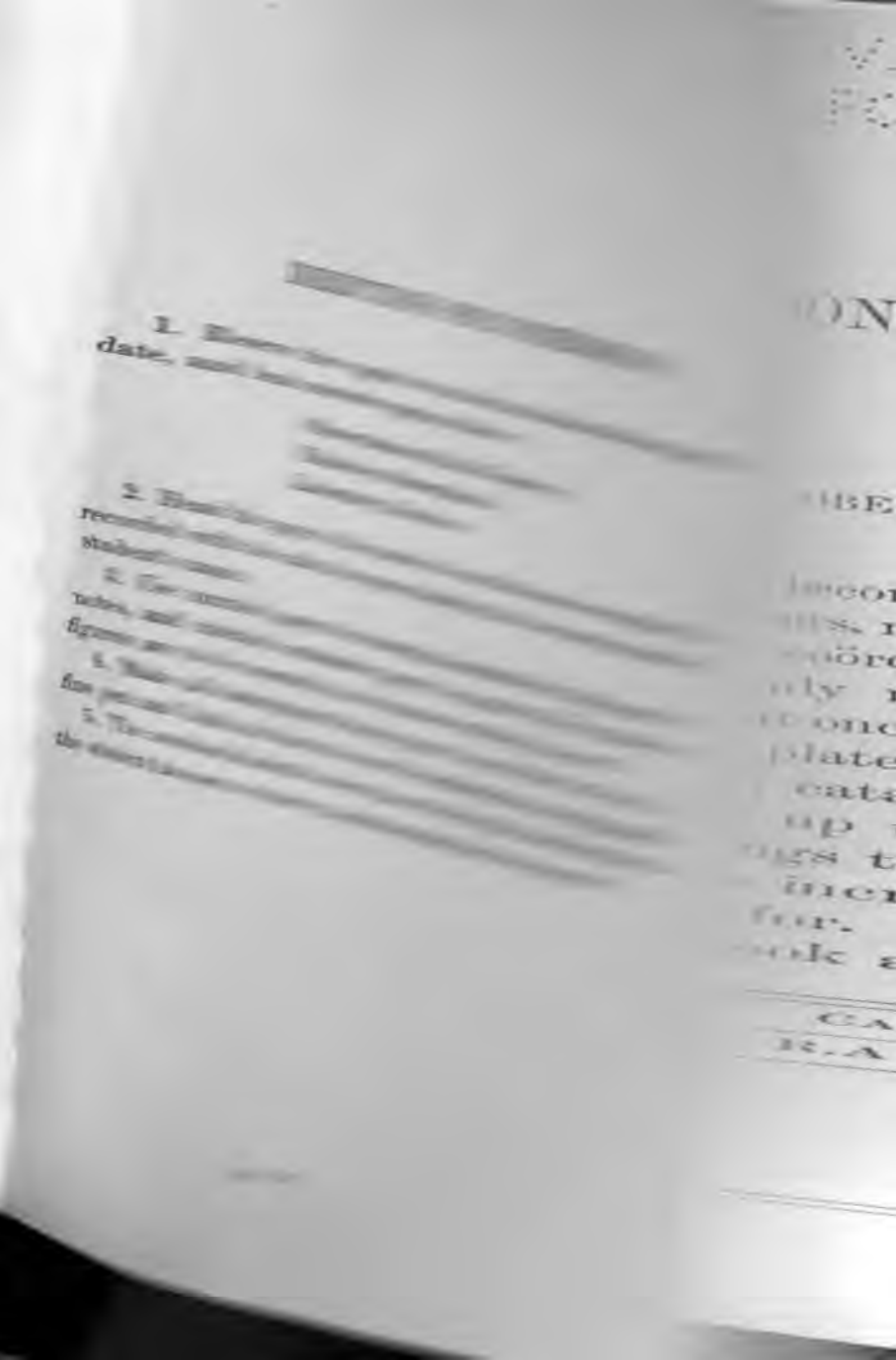
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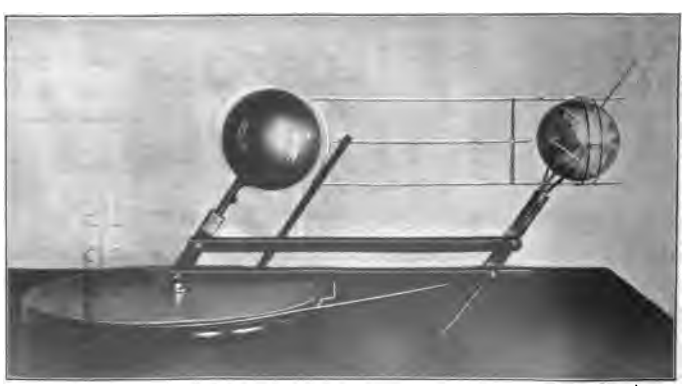

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THE WHITIN OBSERVATORY OF WELLESLEY COLLEGE

Left to right: Bamberg prismatic transit, twelve-inch Clark telescope, concave grating spectroscope, libraries and computing rooms, laboratory with spectrum laboratory below, six-inch Clark telescope, small transit

DAYTIME AND EVENING EXERCISES IN ASTRONOMY

FOR SCHOOLS AND COLLEGES

BY

SARAH FRANCES WHITING, Sc.D.

WHITIN OBSERVATORY, WELLESLEY COLLEGE

GINN AND COMPANY

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TO VIAL
AINSWORTH

The Athenæum Press
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PREFACE

Astronomy is the last of the sciences to use the laboratory method in teaching its elementary classes. The reason of this is not far to seek. Since no instrument has been invented capable of piercing the clouds, observational work has always been dependent on the caprice of the weather. Photography now furnishes perfect representations of sun, moon, planets, and stars, for daytime study; also many forms of illustrative apparatus can be used by the student to awake and cultivate his imagination and furnish, at first-hand, data for scientific reasoning.

This oldest of the sciences, which has heretofore been a rigid discipline for the few, should now take its place beside the others as a training in the scientific method for the many who pursue the subject chiefly for information and culture.

The management of schools and colleges should make the same allowance of time and money for laboratory instruction in this as in the other sciences; there should be a laboratory, a demonstrator, and fixed hours for students' daytime work. Besides the ordinary instruments of an observatory there should be collections of photographs, charts, and apparatus for the students' own handling.

The only astronomical laboratory books known to the writer are those of the South Kensington School of Science in London, and of Miss Byrd and Professor Robert Willson. These admirable handbooks outline comparatively little

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work which can be done in the daytime, the only time which can be controlled independently of the weather.

The following exercises have been proved to be practical by several years' use with classes of sixty to a hundred, handled in divisions of about fifteen, working two hours a week during the academic year.

In this work the student is, whenever possible, left to draw his own conclusions from data discussed. The American Ephemeris is in constant use, photographs of objects in the sky furnish the "specimens" for inspection, and in this subject, as in botany or zoölogy, "sharpening the pencil sharpens the eyes" — to draw the object fixes the attention upon details of structure. The graph is often used to show the relation between variables, and from it the student can often discover for himself great laws.

Moreover the intelligent person, as well as the professional astronomer, should understand the methods by which, through the daytime study of photographs of the sky taken at night, the great advances in astrophysics have been made. In this subject, as in physics, laboratory exercises can show the methods of research and prepare for it. Most plate work must be left for a second-year course, but a few sample exercises are given. The greatest modern advances in astronomy have been made by the spectroscope, and none of these can be discussed with any degree of comprehension without some laboratory work in spectrum analysis. It would be well if in the high schools simple work with the spectroscope were substituted for some of the less "juicy" experiments now included in the beginning course in physics. As it is, no knowledge of the subject can be counted on, and spectroscopes and their accessories should be provided for work in astronomy.

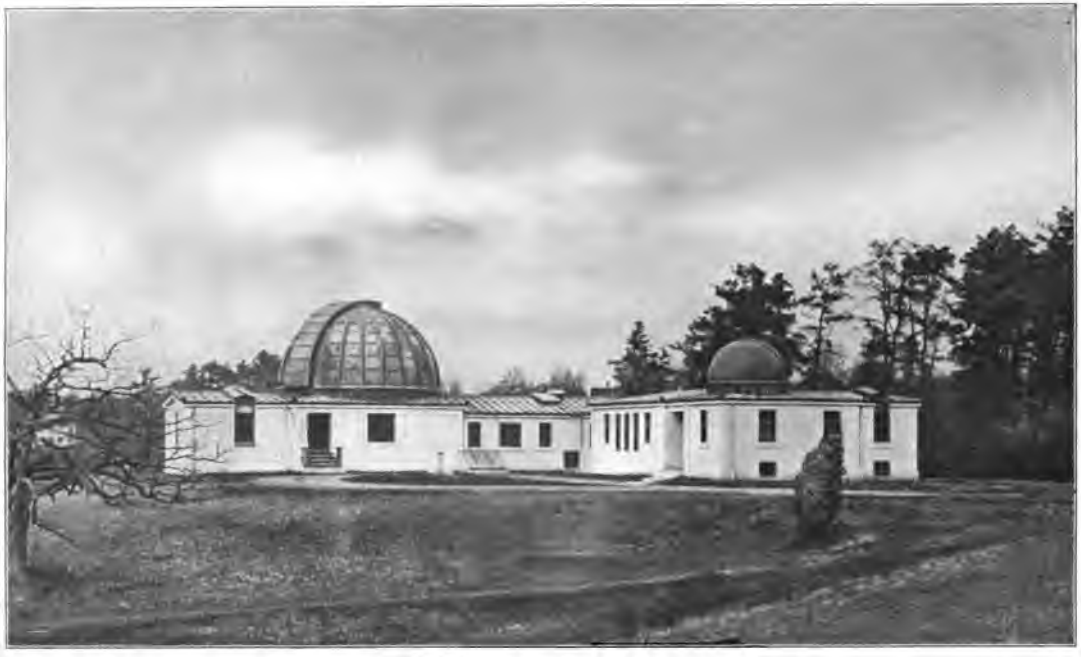
While this daytime work has high value, it cannot for a moment be advocated to take the place of observation in the open. All is but a means to an end, and the student should never be permitted to bend over chart or plot without fully realizing that it is a strip of the sky overhead that he is considering.

By means of daytime preparation, however, the regular program of evening observations can be greatly helped. With this, a short time out of doors, often under circumstances of more or less uncontrollable discomfort, accomplishes wonders. Directions for the record of observations with the telescope are given, with suggestions for the consultation of the Ephemeris or other publications for accurate descriptions and data.

Every student should, of course, be able to identify the constellations in the sky, and to point out objects which a field glass will reveal. The star names and the mythological figures pictured on the old maps should not be omitted, because of the allusions to them which constantly occur in both modern and classic literature. It is best not to study all the constellations at once, but to prepare for observation as they appear in succession during the academic year.

As one looks at the sky the brighter stars seem to form geometrical figures which catch the eye; within and around these the other stars can be found by alignment. It is worth while to become very familiar with these "catch figures" by sketching them on the star atlas with a pencil in the daytime; they are then quickly recognized in the sky at night. The catch figures used in these exercises are those longest in use; many of them from the old atlas of Burritt.

It can be seen then that the ideal equipment for astronomy is an observatory near enough to the centers of



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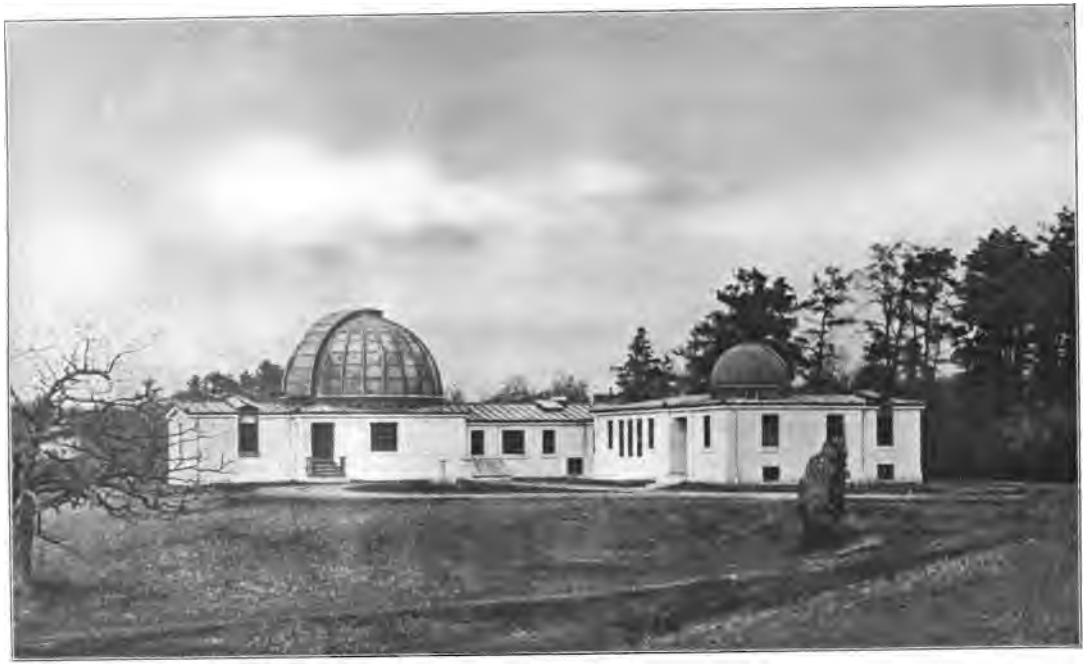

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FOR SCHOOLS AND COLLEGES

BY

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WHITIN OBSERVATORY, WELLESLEY COLLEGE

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I. Apparatus for Illustration

Eighteen-inch celestial globe.
Twelve-inch terrestrial globe.
Andrews's tellurion or McVicar's globe.
Gardner's season apparatus.
Columbia planetarium.
Sun-path model.
Willson's miniature equatorial and altazimuth.
Stonyhurst sun disks.
Serviss's star and planet finder.

The apparatus listed above can be obtained through the J. L. Hammett Company, Boston, Massachusetts.

Lemaire field glass, the diameter of the object glasses twenty-four ligne.
Ives's simplex normal spectroscope.
Browning's miniature direct-vision spectroscope. With this small spectroscope all observations may be taken, even to show the coincidence of the *D* line with the sodium line.
Prism spectroscope and accessories for observing the spectra of the lighter metals.
Induction coil and Plücker tubes for showing spark spectra.
Spektraltafel von Kirchhoff und Bunsen, also the colored charts of Huggins and Miller and of Vögel.
Trouvelot's Atlas of Celestial Objects (out of print, but owned by most observatories).
Durchmusterung des Nordlichen Himmels, with the accompanying text.
Uranometria Argentina (charts of the southern sky).

The field glasses, spectroscopes, and charts are furnished by many apparatus dealers, the charts of the northern sky through dealers in

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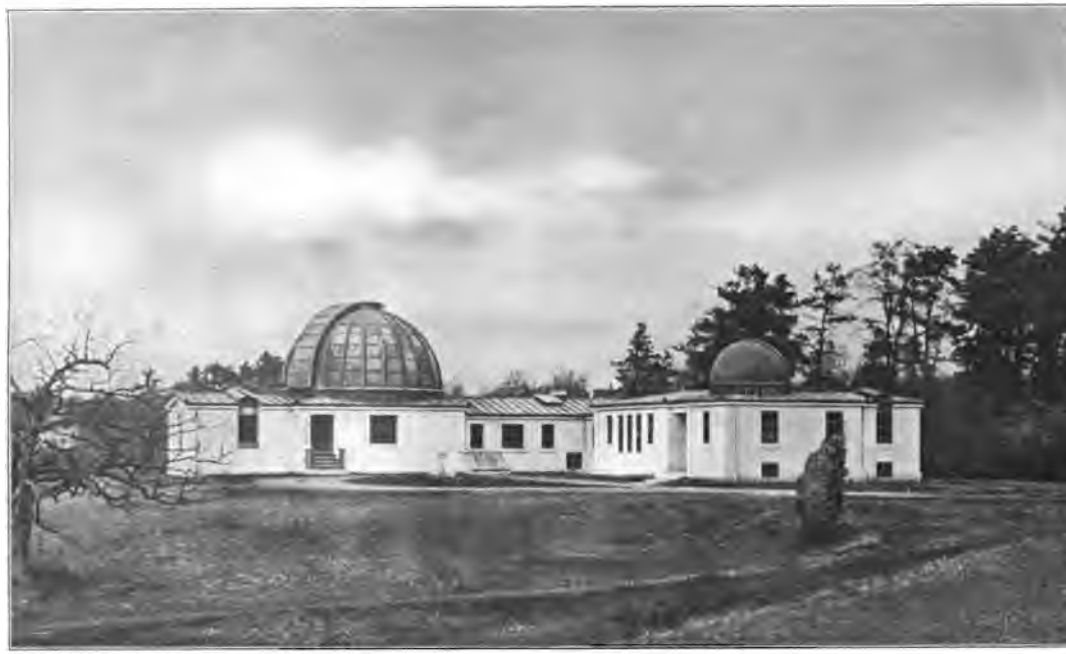

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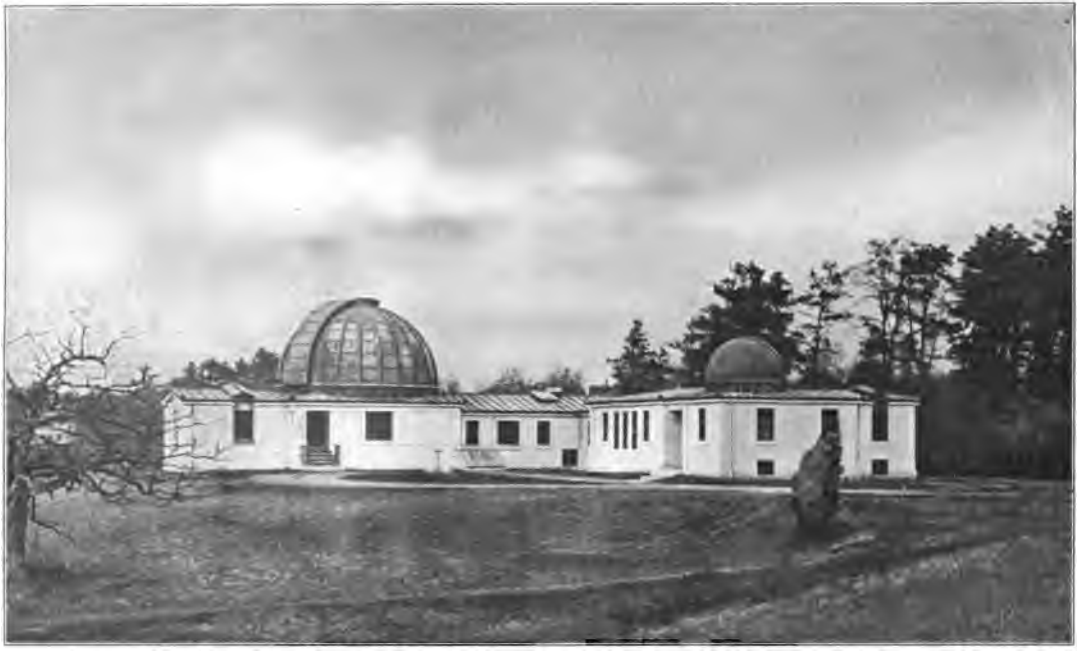

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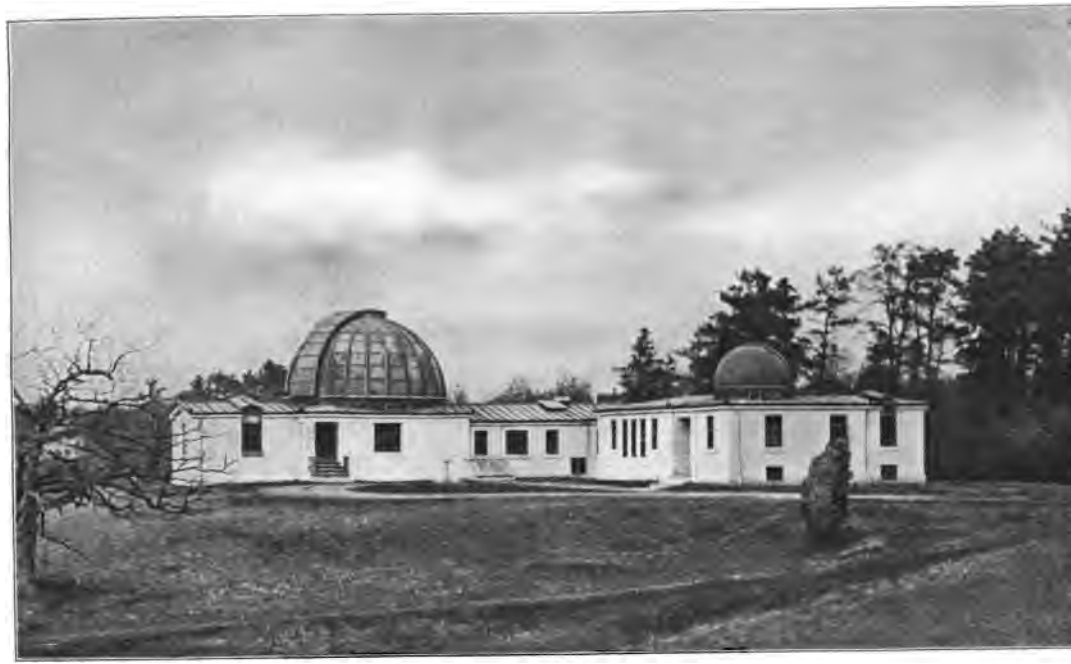

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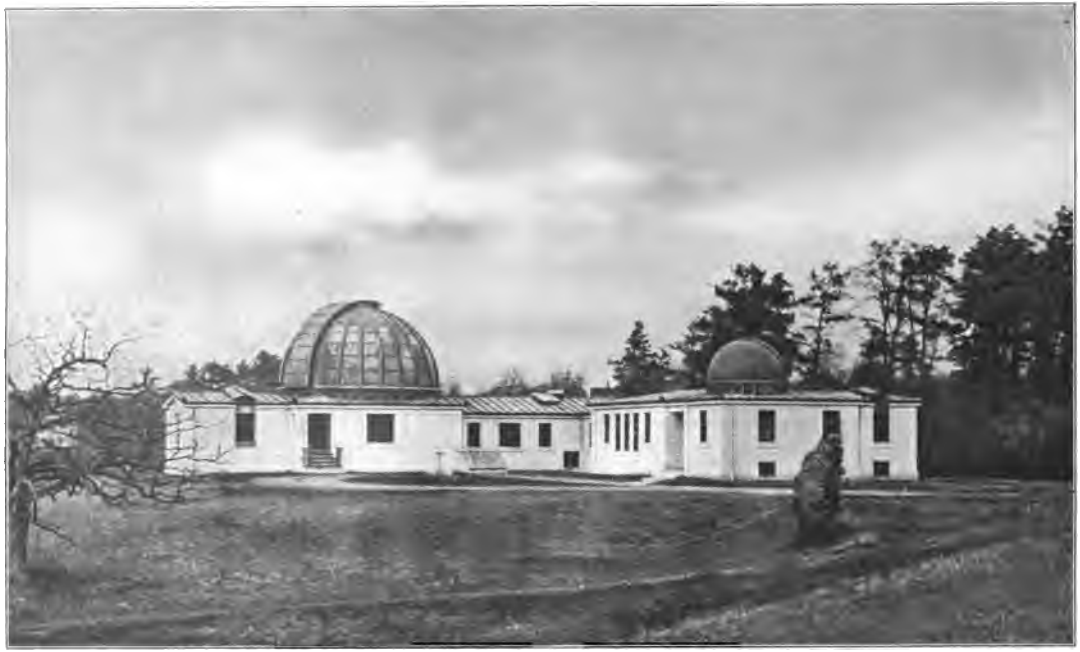

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WHITIN OBSERVATORY, WELLESLEY COLLEGE

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foreign books, the charts of the southern sky through the Cordoba Observatory. Maps of the southern sky in the star atlases can be used if the larger charts are not at hand.

Frame for the illumination of lantern slides.

Screen for projecting sun spots.

These can be made by a carpenter. Sets of lantern slides may often be left for inspection on the support, and changed at intervals. For example, a set showing the complete history of Halley's comet, or famous meteorites, or any other set of pictures which it is desirable to study side by side.

II. Apparatus for Individual Work of Students

Seasonal twilight chart.

Constellation finder.

Six-inch erasable globe.

Hammett's planisphere.

Each student should be supplied with the above apparatus.

Twelve-inch celestial globe.

The solar calculator.

One globe and solar calculator will suffice for each two students.

Colas's map of the moon or the Handy Map of the Moon.

Colas's map of the moon, mounted on cloth, should be tacked to large easels, and one should be provided for each four students.

The American Ephemeris, which can be ordered from the Superintendent of Documents, Washington, D.C.

Viewing-frame for Harvard glass photographs, 8 by 10 inches.

Eyepiece for use with the glass photographs. These can be obtained of the Alvan Clark and Sons Corporation, Cambridgeport, Massachusetts.

Centimeter paper and notebook supplies.

Protractors, compasses, centimeter rulers, paper centimeter scales, etc.

The above apparatus, where not otherwise stated, can be obtained of the J. L. Hammett Company, Boston, Massachusetts. All the apparatus listed is useful and desirable, but selections can be made in beginning a student's laboratory, and additions may be provided from year to year.

LIST OF PHOTOGRAPHS AND GLASS PLATES

Selected regions of the moon: for example, Theophilus–Cyrillus–Katharina; Ptolemy–Alphons–Azachael; Clavius–Tycho; Copernicus; Mare Crisium; Mare Serenitatis; Mare Humorum; Sinus Iridum; the full moon, showing white streaks.

It would be desirable to put into the hands of each student a little booklet of half-tone pictures of different regions of the moon, but this is not yet on the market.

Sun-spot photographs in series, a set for each student.

The Pleiades, with enveloping nebulæ.

Double cluster in Perseus.

Globular cluster in Hercules.

Præsepe in Cancer, as an example of an open cluster.

N. G. C. 2682 in Cancer, as an example of a close cluster.

47 Tucanæ, the region of the Southern Cross, and other photographs of objects in the southern sky.

Messier 5 in Libra.

Two sets of photographs of Messier 5, taken at two different epochs, serve to show the variability of numerous stars in this globular cluster. A pair of these photographs should be provided for each student.

Harvard Map. This is a series of glass chart photographs of the entire sky. The following plates cover the more interesting regions: Numbers 12, 14, 18, 25, 42, 45, 50.

Spectrum plates taken at Harvard Observatory with the objective prism. Interesting plates which contain many types of stars are of the region of the Pleiades, of chi Cygni, of R Cygni, of Wolf-Rayet stars in Cygnus.

Twenty-five selected glass plates of the globular cluster omega Centauri, taken at different epochs. These plates suffice to obtain the light curve of several of the numerous variables in this cluster.

NOTE. The University of Chicago Press sends out a catalogue of photographs taken at Yerkes Observatory. Goodsell Observatory, Northfield, Minnesota, offers a list of celestial photographs. The Georgetown Observatory, Georgetown, D.C., will kindly furnish a limited number of Cestini's drawings of sun spots. The complete Atlas of the Moon, of the Paris Observatory, can be obtained through foreign book dealers. The director of Harvard Observatory shows his practical interest in laboratory astronomy by consenting to furnish plates and photographs at cost as above noted.

DIRECTIONS FOR NOTEBOOKS

1. Reserve three pages for an index, which should be kept up to date, and head successive pages as follows:

Observations with the Telescope.
Naked-eye Observations.
Laboratory Exercises.

2. Head the page of the notebook on which each new exercise is recorded with the date, the proper heading for the exercise, and the student's name.

3. Use unruled paper for drawings, horizontally ruled paper for notes, and checked centimeter paper for graphs. When tables of figures are to be recorded, rule columns vertically in pencil.

4. Make all drawings with sharp pencil; use ink for all else. A fine pen and India ink may be used to advantage in tracing graphs.

5. The notebook should in every case tell briefly and clearly what the student has seen or done; directions should not be copied.

UNIV. OF
CALIFORNIA

EXERCISES IN ASTRONOMY

EXERCISE I

COÖRDINATES OF STARS FROM GLOBE AND STAR CATALOGUE

Object. It is of the greatest importance to become familiar with the two universal coördinates of the stars, right ascension and declination. To measure these coördinates for twenty of the brightest stars will certainly make their meaning clear; moreover, the student will at once learn the names of these stars. It happens that the plates for most globes show the places of the stars given in catalogues for the middle of the last century. By looking up the coördinates of the stars from a catalogue which brings their places down to 1900, the student finds a systematic increase in all the right ascensions which he must account for.

Directions. Make six columns in your notebook as follows:

Constellation	Star Name	Globe		Catalogue	
		R.A.	Dec.	R.A.	Dec.

Write in the first two columns the following list of stars:

Above 0 Magnitude	
Alpha Canis Majoris	Sir'ius
*Alpha Argus	Canō'pus
0 Magnitude	
*Alpha Ērid'ani	Ar'chenar
Alpha Aurī'gæ	Capel'la
Beta Orionis	Rī'gel
Alpha Canis Minoris	Pro'cyon
Alpha Boö'tis	Arctū'rus
*Alpha Centau'ri	
Alpha Lȳ'ræ	Vē'ga
1st Magnitude	
Alpha Tauri	Aldeb'aran
Alpha Orionis	Bet'elguese (gerz)
Beta Geminorum	Pol'lux
Alpha Leonis	Reg'ulus
*Alpha Crucis	
Alpha Virginis	Spī'ca
*Beta Centauri	
Alpha Scorpii	Antā'res
Alpha Aq'uilæ	Altair'
Alpha Cygni	Den'eb
Alpha Piscis Austrā'lis	Fo'malhaut

Next, with a flexible scale of brass, or better, of paper measure on the globe the right ascension and declination of each of these stars, and record in the third and fourth columns.

Finally, look up these stars in the "Catalogue of 152 Bright Stars" from the Harvard Annals, or in the American Ephemeris, or in some catalogue which gives places for 1900.

* The five stars marked with an asterisk are invisible in intermediate northern latitudes.

Remembering that the places on the globe are for the epoch 1850, and that those of the catalogue are for 1900, record in your notebook answers to the following questions:

1. How do the right ascensions as you measure them compare with those from the catalogue?

2. In what two ways might you account for the difference?

3. Which of the two ways is more rational?

NOTE. Hipparchus discovered the precession of the equinoxes in 150 B.C.

EXERCISE II

PROBLEMS TO BE SOLVED BY GLOBES

Object. No chart can give so perfect a representation of the sky as a globe, but the globe has the disadvantage that the observer is looking at the celestial sphere from the outside instead of from the center. Solving a few problems with the globes overcomes this difficulty, and the student finds that a radius of the globe passing through the star on its surface, and extended to the celestial sphere, finds the true star.

Directions. Identify the parts of the celestial globe:

1. The artificial horizon, consisting of the amplitude circle, the azimuth circle, the points of the compass, the signs of the zodiac, the degrees of each sign, the dates of the month.

2. The celestial equator on which the right ascension is reckoned in hours from 1 to 24; the ecliptic on which the signs of the zodiac, each 30°, are marked.

3. The vernal and autumnal equinoxes; summer and winter solstices; zenith and nadir; north, south, east, and west points; the north pole and south pole.

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Rī'gel
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3. The vernal and autumnal equinoxes; summer and winter solstices; zenith and nadir; north, south, east, and west points; the north pole and south pole.

4. The twenty-four hour circles perpendicular to the equator.

5. The brass meridian, passing through the poles of the globe, perpendicular both to the equator and the horizon. By revolving this circle the pole may be set to any elevation, so that the globe may represent the appearance of the heavens at any latitude.

6. A flexible strip graduated in degrees, which may be used to read altitudes.

Problems. 1. Set the globe to show three positions of the sphere with reference to the horizon.

a. The right sphere. Set the poles in the horizon. Note that in this position, which is found perfectly at the equator and approximately anywhere in the tropics, all the stars rise and set each day and move in circles perpendicular to the horizon.

b. The parallel sphere. Set the poles in the zenith and nadir. In this position, which is found perfectly at the poles and approximately within the polar circles, half the stars are above the horizon the whole twenty-four hours, and the other half never rise above the horizon.

c. The oblique sphere. Set the north pole at an elevation above the horizon of 45° and note that the celestial sphere is now divided into three portions: namely, all the stars within 45° of the north pole are above the horizon the whole twenty-four hours; all the stars within 45° of the south pole never rise above the horizon; all the stars of any declination between, rise and set every day.

2. Find the time of sunrise and of sunset, also the length of day at any place at any date.

Elevate the pole a number of degrees equal to the latitude of the place. Find the place of the sun on the given

date by the artificial horizon; that is, find the date and the degree and sign opposite. This is the position of the sun in the ecliptic on the day in question. Find this position on the ecliptic and bring it to the meridian. The globe now represents the appearance of the heavens at noon on the day in question. Now turn the globe until the sun is on the eastern horizon, counting the number of hour circles which pass the meridian. This shows the number of hours between sunrise and noon. Find the time of sunrise, sunset, and the length of daylight at the solstices and equinoxes at the following places: Boston, latitude 42°; London, latitude 52°; the North Cape, latitude 70°. Record the results in columns headed

PLACE	LATITUDE	DATE	SUNRISE	SUNSET	LENGTH OF DAY

3. Represent the appearance of the heavens at any time, for instance, nine o'clock on any date, at a given place.

Set the globe for the place, and find the sun's position on the ecliptic for the date, and place this under the meridian. Turn the globe west, past nine hour circles; then record what constellations are just rising east, setting west, and on the meridian. Thus study the appearance of the heavens at your station at nine o'clock on October 1, January 1, April 1, July 1.

4. Find at what date Sirius will be rising in the east as the sun sets in the west; at what date Sirius will be on the meridian at midnight. Answer the same questions for Arcturus.

EXERCISE III

STUDY OF SEASONS BY GARDNER'S SEASON APPARATUS

NOTE. Demonstrations with the apparatus referred to in this and the following exercise should be given by the instructor. Students should record in their notebooks all observations and answers to questions.

Directions. After a description of the apparatus has been given by the instructor, the globe should be separately revolved to show each point.

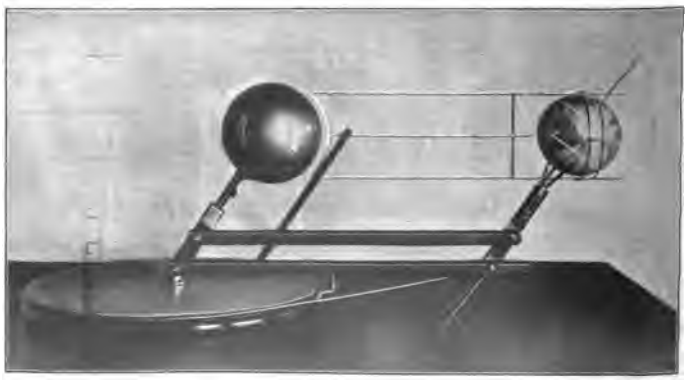

FIG. 1. GARDNER'S SEASON APPARATUS

1. Demonstration of parallelism of axis. Show that in the northern hemisphere in June the axis makes an acute angle with the perpendicular ray from the sun, in September a right angle, in December an obtuse angle, and in March a right angle again.

2. Demonstration of the relation of the circle of illumination to circles of diurnal rotation at the different seasons,

and the consequent length of day and night and amount of heat received.

3. Demonstration of the advance of the oblique ray northward in winter.

4. Demonstration of the tropics and polar circles. The slate globe and chalk may be used for this.

Answer in the notebook the following questions:

1. Towards what point in the sky does the north extremity of the earth's axis point?

2. State the angle which the axis makes with the perpendicular ray from the sun at different times of the year.

3. Define the circle of illumination and state its relation to the circles of diurnal rotation at different times of the year.

4. State when the days and nights are of equal length, and give reasons.

5. State the reason of the long polar daylight and darkness.

6. State the length of the day and of the night at the equator at different seasons.

EXERCISE IV

STUDY OF TWILIGHT BY McVICAR'S GLOBE

NOTE. If the more expensive and elaborate piece of apparatus, the McVicar's globe, is possessed, it can be used for all demonstrations of the parallelism of the axis of the earth and the seasons, but it is especially valuable to show very strikingly the varying duration of twilight from the equator to the pole.

Directions. Set the horizon twilight frame with its zenith over the place it is desired to study (directions accompany

the globe); clamp the frame and revolve the globe. It will be seen that in high latitudes the twilight belt at the summer solstice is traversed nearly all night by the sun.

FIG. 2. McVICAR'S GLOBE

In the same way show the shortness of twilight at the equator, on account of the perpendicular path across the twilight belt, and the duration of twilight for months at the pole.

It is especially interesting to set the twilight frame for London or Edinburgh, or places in Norway, and to note the reason for the long summer twilights so noticeable to tourists. The very short twilights in places near the equator remarked by tourists to Cuba or Panama may well be demonstrated.

EXERCISE V

STUDIES WITH THE SEASONAL TWILIGHT CHART

NOTE. This exercise consists of two parts, — drawings by the student, and studies by the use of the chart.

Before any work is attempted by the student the instructor should set up a globe and show how the chart is a projection of the celestial sphere on the meridian, from a point of observation due east in the plane of the horizon. The Sun-path Model, set sideways, shows perhaps even better what is meant by the orthographic projection in the plane of the meridian.

Material. Seasonal Twilight Chart, unruled paper, compasses, protractor, also globe and Sun-path Model.

Directions for drawings. 1. On three sheets of paper make circles fifteen centimeters in diameter. Through the center of each draw two diameters at right angles. Use the protractor to make these diameters perpendicular. Mark the horizontal diameter, which represents the horizon projected in a straight line *HO*; and the vertical one, which is the prime vertical *ZN*. With the protractor measure on the meridian, below the horizon on each side, an angle of 18°, and draw the small circle which is called "the twilight circle."

2. Complete the figure to represent the conditions in different latitudes as follows:

Measure an angle above the horizon on the north, equal to the latitude of the place, and mark it *P*. Through it and the center draw *PP*, the six-o'clock hour circle projected in a straight line.

Measure angles above the horizon on the south, and below on the north, equal to the complement of the latitude, and draw *EQ*, the equator projected in a straight line. Observe the relation *EQ* to *PP*.

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Measure on the meridian, both above and below *EQ*, angles equal to the sun's declination at the solstices, namely 23°.5. Draw the diurnal path of the sun at these times. Print in small letters on these diurnal circles the dates when the sun is on them.

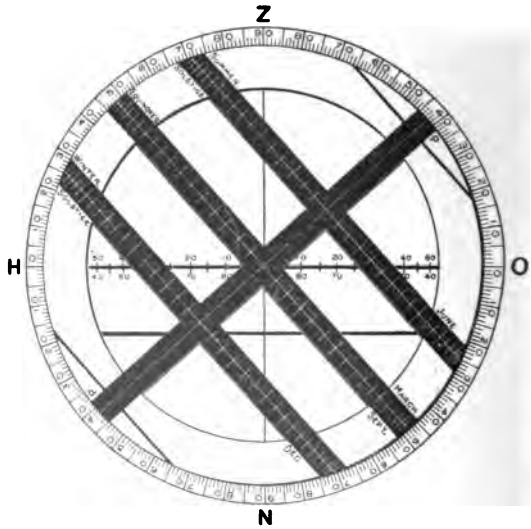

FIG. 3. SEASONAL TWILIGHT CHART

Complete projections for the following latitudes: latitude 72°, the North Cape, within the polar circle; latitude 90°, the pole; the observer's latitude.

Directions for use of chart. With the chart study the following conditions:

1. Latitude 0°, the equator. This will approximately represent conditions at Quito, Singapore, Lake Victoria Nyanza. Note that in these places the north-pole star will be in the horizon.

2. Latitude +23°.5, the northern tropic, near which are situated Havana, Sandwich Islands, Hongkong, Calcutta, Assouan.

3. Latitude 48°.5, nearly the latitude of Paris, Quebec, Vancouver.

4. Latitude 66°.5, the polar circle, near which are Archangel, Iceland, Bering Strait.

Inspect the drawings or the chart and answer the following questions:

1. In latitude 0° how are the twenty-four hours divided?

2. How does the length of day compare with the length of night?

3. How long is twilight at the equinoxes?

4. What is the noon altitude of the sun at the equinoxes? at the summer solstice? at the winter solstice?

5. In latitude 72° what is the length of day at the summer solstice? what is the midnight altitude of the sun? How are the twenty-four hours divided at the equinoxes? at the winter solstice?

6. In latitude 90° discuss the length of day, of twilight, and of night, at the summer and winter solstices and at the equinoxes.

7. What is the sun's altitude in latitude 90° at the summer solstice? How would the sun appear to move that day with reference to the horizon? What would be the form of its path as it gradually sinks to the horizon?

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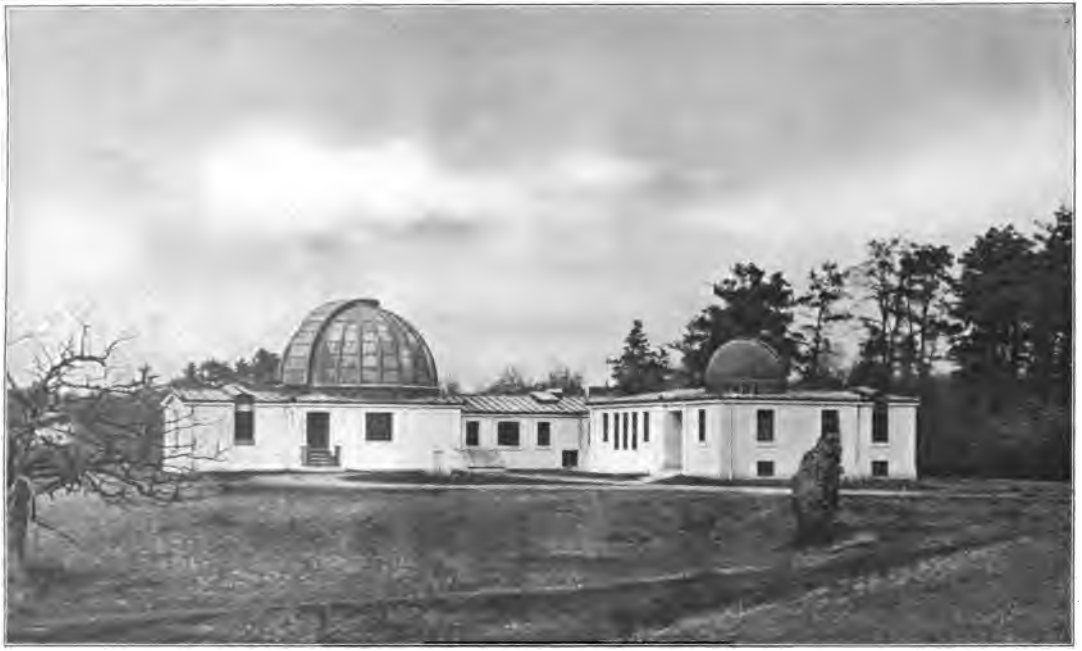

THE WHITIN OBSERVATORY OF WELLESLEY COLLEGE

Left to right: Bamberg prismatic transit, twelve-inch Clark telescope, concave grating spectroscope, libraries and computing rooms, laboratory with spectrum laboratory below, six-inch Clark telescope, small transit

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FOR SCHOOLS AND COLLEGES

BY

SARAH FRANCES WHITING, Sc.D.

WHITIN OBSERVATORY, WELLESLEY COLLEGE

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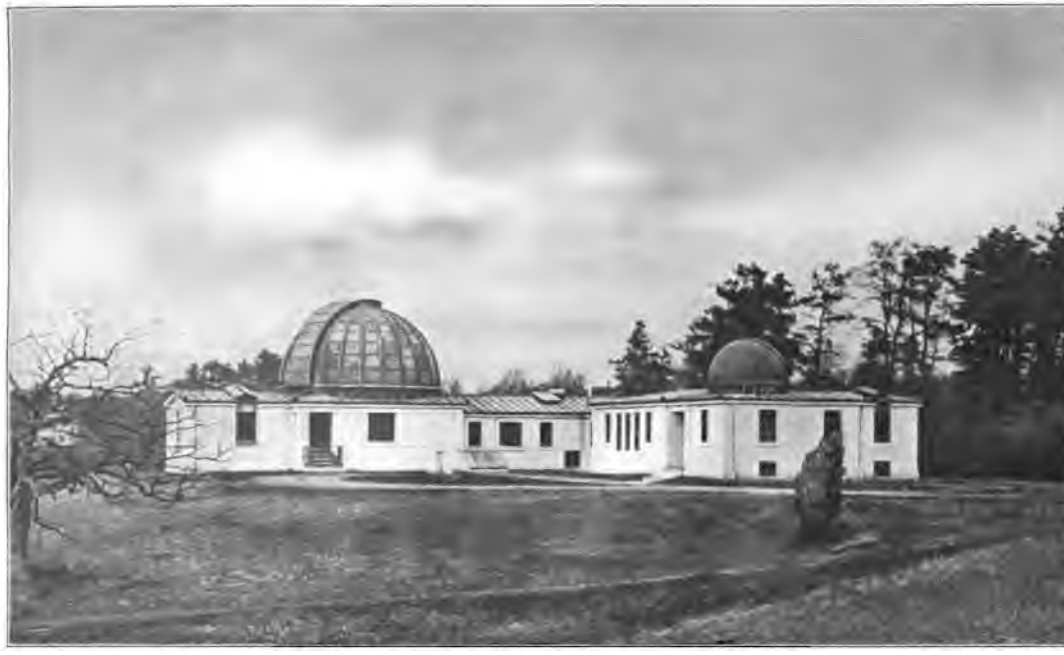

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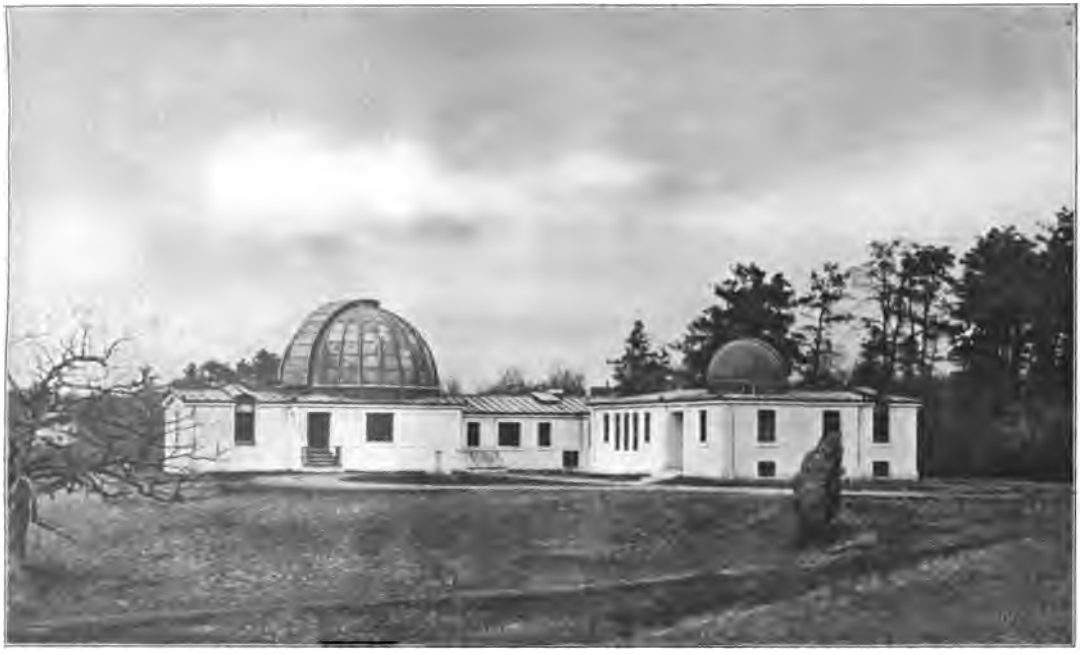

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This oldest of the sciences, which has heretofore been a rigid discipline for the few, should now take its place beside the others as a training in the scientific method for the many who pursue the subject chiefly for information and culture.

The management of schools and colleges should make the same allowance of time and money for laboratory instruction in this as in the other sciences; there should be a laboratory, a demonstrator, and fixed hours for students' daytime work. Besides the ordinary instruments of an observatory there should be collections of photographs, charts, and apparatus for the students' own handling.

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Suggestions for these exercises have come from many sources through a long period. Professor Pickering, director of Harvard Observatory, who opened the first students' laboratory in physics, inspired the writer to attempt students' daytime work in astronomy. General acknowledgment is hereby made for all help, and the hope expressed that these exercises may form a slight contribution to the better teaching of the only science dealing with matter which takes thought off this little planet, and gives those larger conceptions of time and space which stretch the mind and furnish proper perspective for other subjects.

SARAH F. WHITING

WHITIN OBSERVATORY, WELLESLEY COLLEGE

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LIST OF APPARATUS

I. Apparatus for Illustration

Eighteen-inch celestial globe.
Twelve-inch terrestrial globe.
Andrews's tellurion or McVicar's globe.
Gardner's season apparatus.
Columbia planetarium.
Sun-path model.
Willson's miniature equatorial and altazimuth.
Stonyhurst sun disks.
Serviss's star and planet finder.

The apparatus listed above can be obtained through the J. L. Hammett Company, Boston, Massachusetts.

Lemaire field glass, the diameter of the object glasses twenty-four ligne.
Ives's simplex normal spectroscope.
Browning's miniature direct-vision spectroscope. With this small spectroscope all observations may be taken, even to show the coincidence of the *D* line with the sodium line.
Prism spectroscope and accessories for observing the spectra of the lighter metals.
Induction coil and Plücker tubes for showing spark spectra.
Spektraltafel von Kirchhoff und Bunsen, also the colored charts of Huggins and Miller and of Vögel.
Trouvelot's Atlas of Celestial Objects (out of print, but owned by most observatories).
Durchmusterung des Nordlichen Himmels, with the accompanying text.
Uranometria Argentina (charts of the southern sky).

The field glasses, spectroscopes, and charts are furnished by many apparatus dealers, the charts of the northern sky through dealers in

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Prism spectroscope and accessories for observing the spectra of the lighter metals.
Induction coil and Plücker tubes for showing spark spectra.
Spektraltafel von Kirchhoff und Bunsen, also the colored charts of Huggins and Miller and of Vögel.
Trouvelot's Atlas of Celestial Objects (out of print, but owned by most observatories).
Durchmusterung des Nordlichen Himmels, with the accompanying text.
Uranometria Argentina (charts of the southern sky).

The field glasses, spectroscopes, and charts are furnished by many apparatus dealers, the charts of the northern sky through dealers in

foreign books, the charts of the southern sky through the Cordoba Observatory. Maps of the southern sky in the star atlases can be used if the larger charts are not at hand.

Frame for the illumination of lantern slides.

Screen for projecting sun spots.

These can be made by a carpenter. Sets of lantern slides may often be left for inspection on the support, and changed at intervals. For example, a set showing the complete history of Halley's comet, or famous meteorites, or any other set of pictures which it is desirable to study side by side.

II. Apparatus for Individual Work of Students

Seasonal twilight chart.

Constellation finder.

Six-inch erasable globe.

Hammett's planisphere.

Each student should be supplied with the above apparatus.

Twelve-inch celestial globe.

The solar calculator.

One globe and solar calculator will suffice for each two students.

Colas's map of the moon or the Handy Map of the Moon.

Colas's map of the moon, mounted on cloth, should be tacked to large easels, and one should be provided for each four students.

The American Ephemeris, which can be ordered from the Superintendent of Documents, Washington, D.C.

Viewing-frame for Harvard glass photographs, 8 by 10 inches.

Eyepiece for use with the glass photographs. These can be obtained of the Alvan Clark and Sons Corporation, Cambridgeport, Massachusetts.

Centimeter paper and notebook supplies.

Protractors, compasses, centimeter rulers, paper centimeter scales, etc.

The above apparatus, where not otherwise stated, can be obtained of the J. L. Hammett Company, Boston, Massachusetts. All the apparatus listed is useful and desirable, but selections can be made in beginning a student's laboratory, and additions may be provided from year to year.

LIST OF PHOTOGRAPHS AND GLASS PLATES

Selected regions of the moon: for example, Theophilus–Cyrillus–Katharina; Ptolemy–Alphons–Azachael; Clavius–Tycho; Copernicus; Mare Crisium; Mare Serenitatis; Mare Humorum; Sinus Iridum; the full moon, showing white streaks.

It would be desirable to put into the hands of each student a little booklet of half-tone pictures of different regions of the moon, but this is not yet on the market.

Sun-spot photographs in series, a set for each student.

The Pleiades, with enveloping nebulæ.

Double cluster in Perseus.

Globular cluster in Hercules.

Præsepe in Cancer, as an example of an open cluster.

N. G. C. 2682 in Cancer, as an example of a close cluster.

47 Tucanæ, the region of the Southern Cross, and other photographs of objects in the southern sky.

Messier 5 in Libra.

Two sets of photographs of Messier 5, taken at two different epochs, serve to show the variability of numerous stars in this globular cluster. A pair of these photographs should be provided for each student.

Harvard Map. This is a series of glass chart photographs of the entire sky. The following plates cover the more interesting regions: Numbers 12, 14, 18, 25, 42, 45, 50.

Spectrum plates taken at Harvard Observatory with the objective prism. Interesting plates which contain many types of stars are of the region of the Pleiades, of chi Cygni, of R Cygni, of Wolf-Rayet stars in Cygnus.

Twenty-five selected glass plates of the globular cluster omega Centauri, taken at different epochs. These plates suffice to obtain the light curve of several of the numerous variables in this cluster.

NOTE. The University of Chicago Press sends out a catalogue of photographs taken at Yerkes Observatory. Goodsell Observatory, Northfield, Minnesota, offers a list of celestial photographs. The Georgetown Observatory, Georgetown, D.C., will kindly furnish a limited number of Cestini's drawings of sun spots. The complete Atlas of the Moon, of the Paris Observatory, can be obtained through foreign book dealers. The director of Harvard Observatory shows his practical interest in laboratory astronomy by consenting to furnish plates and photographs at cost as above noted.

DIRECTIONS FOR NOTEBOOKS

1. Reserve three pages for an index, which should be kept up to date, and head successive pages as follows:

Observations with the Telescope.
Naked-eye Observations.
Laboratory Exercises.

2. Head the page of the notebook on which each new exercise is recorded with the date, the proper heading for the exercise, and the student's name.

3. Use unruled paper for drawings, horizontally ruled paper for notes, and checked centimeter paper for graphs. When tables of figures are to be recorded, rule columns vertically in pencil.

4. Make all drawings with sharp pencil; use ink for all else. A fine pen and India ink may be used to advantage in tracing graphs.

5. The notebook should in every case tell briefly and clearly what the student has seen or done; directions should not be copied.

UNIV. OF CALIFORNIA

EXERCISES IN ASTRONOMY

EXERCISE I

COÖRDINATES OF STARS FROM GLOBE AND STAR CATALOGUE

Object. It is of the greatest importance to become familiar with the two universal coördinates of the stars, right ascension and declination. To measure these coördinates for twenty of the brightest stars will certainly make their meaning clear; moreover, the student will at once learn the names of these stars. It happens that the plates for most globes show the places of the stars given in catalogues for the middle of the last century. By looking up the coördinates of the stars from a catalogue which brings their places down to 1900, the student finds a systematic increase in all the right ascensions which he must account for.

Directions. Make six columns in your notebook as follows:

CONSTELLATION	STAR NAME	GLOBE		CATALOGUE	
		R.A.	DEC.	R.A.	DEC.

Write in the first two columns the following list of stars:

Above 0 Magnitude	
Alpha Canis Majoris	Sir'ius
*Alpha Argus	Canō'pus
0 Magnitude	
*Alpha Ērid'ani	Ar'chenar
Alpha Aurī'gæ	Capel'la
Beta Orionis	Rī'gel
Alpha Canis Minoris	Pro'cyon
Alpha Boö'tis	Arctū'rus
*Alpha Centau'ri	
Alpha Lȳ'ræ	Vē'ga
1st Magnitude	
Alpha Tauri	Aldeb'aran
Alpha Orionis	Bet'elguese (gerz)
Beta Geminorum	Pol'lux
Alpha Leonis	Reg'ulus
*Alpha Crucis	
Alpha Virginis	Spī'ca
*Beta Centauri	
Alpha Scorpii	Antā'res
Alpha Aq'uilæ	Altair'
Alpha Cygni	Den'eb
Alpha Piscis Austrā'lis	Fo'malhaut

Next, with a flexible scale of brass, or better, of paper, measure on the globe the right ascension and declination of each of these stars, and record in the third and fourth columns.

Finally, look up these stars in the "Catalogue of 1520 Bright Stars" from the Harvard Annals, or in the American Ephemeris, or in some catalogue which gives places for 1900.

* The five stars marked with an asterisk are invisible in intermediate northern latitudes.

Remembering that the places on the globe are for the epoch 1850, and that those of the catalogue are for 1900, record in your notebook answers to the following questions:

1. How do the right ascensions as you measure them compare with those from the catalogue?

2. In what two ways might you account for the difference?

3. Which of the two ways is more rational?

NOTE. Hipparchus discovered the precession of the equinoxes in 150 B.C.

EXERCISE II

PROBLEMS TO BE SOLVED BY GLOBES

Object. No chart can give so perfect a representation of the sky as a globe, but the globe has the disadvantage that the observer is looking at the celestial sphere from the outside instead of from the center. Solving a few problems with the globes overcomes this difficulty, and the student finds that a radius of the globe passing through the star on its surface, and extended to the celestial sphere, finds the true star.

Directions. Identify the parts of the celestial globe:

1. The artificial horizon, consisting of the amplitude circle, the azimuth circle, the points of the compass, the signs of the zodiac, the degrees of each sign, the dates of the month.

2. The celestial equator on which the right ascension is reckoned in hours from 1 to 24; the ecliptic on which the signs of the zodiac, each 30°, are marked.

3. The vernal and autumnal equinoxes; summer and winter solstices; zenith and nadir; north, south, east, and west points; the north pole and south pole.

4. The twenty-four hour circles perpendicular to the equator.

5. The brass meridian, passing through the poles of the globe, perpendicular both to the equator and the horizon. By revolving this circle the pole may be set to any elevation, so that the globe may represent the appearance of the heavens at any latitude.

6. A flexible strip graduated in degrees, which may be used to read altitudes.

Problems. 1. Set the globe to show three positions of the sphere with reference to the horizon.

a. The right sphere. Set the poles in the horizon. Note that in this position, which is found perfectly at the equator and approximately anywhere in the tropics, all the stars rise and set each day and move in circles perpendicular to the horizon.

b. The parallel sphere. Set the poles in the zenith and nadir. In this position, which is found perfectly at the poles and approximately within the polar circles, half the stars are above the horizon the whole twenty-four hours, and the other half never rise above the horizon.

c. The oblique sphere. Set the north pole at an elevation above the horizon of 45° and note that the celestial sphere is now divided into three portions: namely, all the stars within 45° of the north pole are above the horizon the whole twenty-four hours; all the stars within 45° of the south pole never rise above the horizon; all the stars of any declination between, rise and set every day.

2. Find the time of sunrise and of sunset, also the length of day at any place at any date.

Elevate the pole a number of degrees equal to the latitude of the place. Find the place of the sun on the given

date by the artificial horizon; that is, find the date and the degree and sign opposite. This is the position of the sun in the ecliptic on the day in question. Find this position on the ecliptic and bring it to the meridian. The globe now represents the appearance of the heavens at noon on the day in question. Now turn the globe until the sun is on the eastern horizon, counting the number of hour circles which pass the meridian. This shows the number of hours between sunrise and noon. Find the time of sunrise, sunset, and the length of daylight at the solstices and equinoxes at the following places: Boston, latitude 42°; London, latitude 52°; the North Cape, latitude 70°. Record the results in columns headed

PLACE	LATITUDE	DATE	SUNRISE	SUNSET	LENGTH OF DAY

3. Represent the appearance of the heavens at any time, for instance, nine o'clock on any date, at a given place.

Set the globe for the place, and find the sun's position on the ecliptic for the date, and place this under the meridian. Turn the globe west, past nine hour circles; then record what constellations are just rising east, setting west, and on the meridian. Thus study the appearance of the heavens at your station at nine o'clock on October 1, January 1, April 1, July 1.

4. Find at what date Sirius will be rising in the east as the sun sets in the west; at what date Sirius will be on the meridian at midnight. Answer the same questions for Arcturus.

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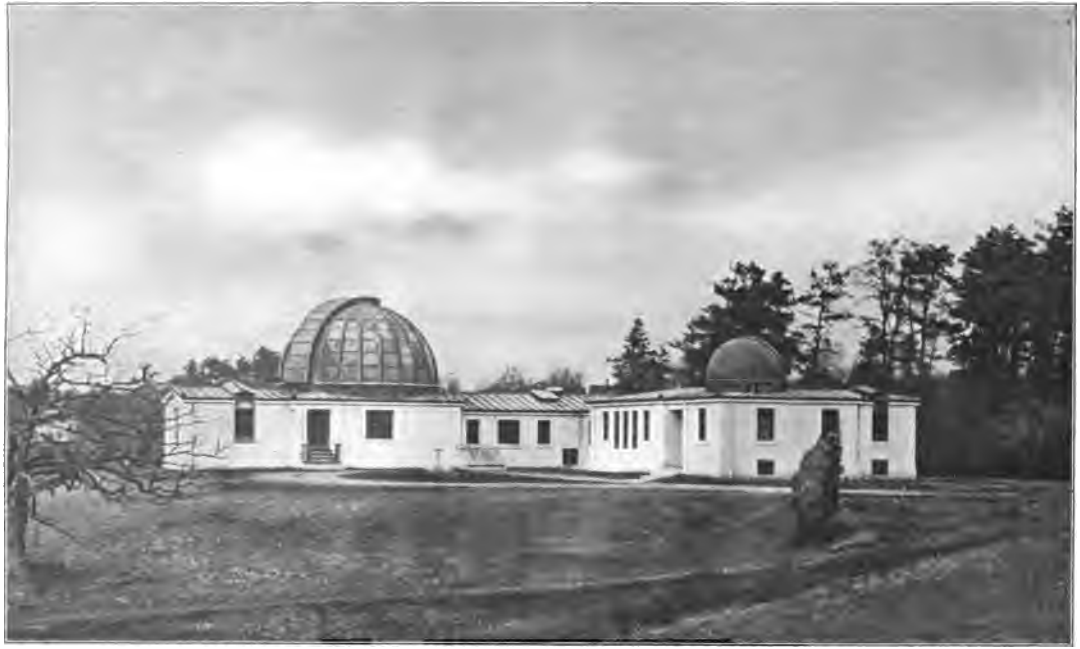

THE WHITIN OBSERVATORY OF WELLESLEY COLLEGE

Left to right: Bamberg prismatic transit, twelve-inch Clark telescope, concave grating spectroscope, libraries and computing rooms, laboratory with spectrum laboratory below, six-inch Clark telescope, small transit

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FOR SCHOOLS AND COLLEGES

BY

SARAH FRANCES WHITING, Sc.D.

WHITIN OBSERVATORY, WELLESLEY COLLEGE

UNIV. OF CALIFORNIA

GINN AND COMPANY

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PREFACE

Astronomy is the last of the sciences to use the laboratory method in teaching its elementary classes. The reason of this is not far to seek. Since no instrument has been invented capable of piercing the clouds, observational work has always been dependent on the caprice of the weather. Photography now furnishes perfect representations of sun, moon, planets, and stars, for daytime study; also many forms of illustrative apparatus can be used by the student to awake and cultivate his imagination and furnish, at first-hand, data for scientific reasoning.

This oldest of the sciences, which has heretofore been a rigid discipline for the few, should now take its place beside the others as a training in the scientific method for the many who pursue the subject chiefly for information and culture.

The management of schools and colleges should make the same allowance of time and money for laboratory instruction in this as in the other sciences; there should be a laboratory, a demonstrator, and fixed hours for students' daytime work. Besides the ordinary instruments of an observatory there should be collections of photographs, charts, and apparatus for the students' own handling.

The only astronomical laboratory books known to the writer are those of the South Kensington School of Science in London, and of Miss Byrd and Professor Robert Willson. These admirable handbooks outline comparatively little

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work which can be done in the daytime, the only time which can be controlled independently of the weather.

The following exercises have been proved to be practical by several years' use with classes of sixty to a hundred, handled in divisions of about fifteen, working two hours a week during the academic year.

In this work the student is, whenever possible, left to draw his own conclusions from data discussed. The American Ephemeris is in constant use, photographs of objects in the sky furnish the "specimens" for inspection, and in this subject, as in botany or zoölogy, "sharpening the pencil sharpens the eyes" — to draw the object fixes the attention upon details of structure. The graph is often used to show the relation between variables, and from it the student can often discover for himself great laws.

Moreover the intelligent person, as well as the professional astronomer, should understand the methods by which, through the daytime study of photographs of the sky taken at night, the great advances in astrophysics have been made. In this subject, as in physics, laboratory exercises can show the methods of research and prepare for it. Most plate work must be left for a second-year course, but a few sample exercises are given. The greatest modern advances in astronomy have been made by the spectroscope, and none of these can be discussed with any degree of comprehension without some laboratory work in spectrum analysis. It would be well if in the high schools simple work with the spectroscope were substituted for some of the less "juicy" experiments now included in the beginning course in physics. As it is, no knowledge of the subject can be counted on, and spectroscopes and their accessories should be provided for work in astronomy.

While this daytime work has high value, it cannot for a moment be advocated to take the place of observation in the open. All is but a means to an end, and the student should never be permitted to bend over chart or plot without fully realizing that it is a strip of the sky overhead that he is considering.

By means of daytime preparation, however, the regular program of evening observations can be greatly helped. With this, a short time out of doors, often under circumstances of more or less uncontrollable discomfort, accomplishes wonders. Directions for the record of observations with the telescope are given, with suggestions for the consultation of the Ephemeris or other publications for accurate descriptions and data.

Every student should, of course, be able to identify the constellations in the sky, and to point out objects which a field glass will reveal. The star names and the mythological figures pictured on the old maps should not be omitted, because of the allusions to them which constantly occur in both modern and classic literature. It is best not to study all the constellations at once, but to prepare for observation as they appear in succession during the academic year.

As one looks at the sky the brighter stars seem to form geometrical figures which catch the eye; within and around these the other stars can be found by alignment. It is worth while to become very familiar with these "catch figures" by sketching them on the star atlas with a pencil in the daytime; they are then quickly recognized in the sky at night. The catch figures used in these exercises are those longest in use; many of them from the old atlas of Burritt.

It can be seen then that the ideal equipment for astronomy is an observatory near enough to the centers of

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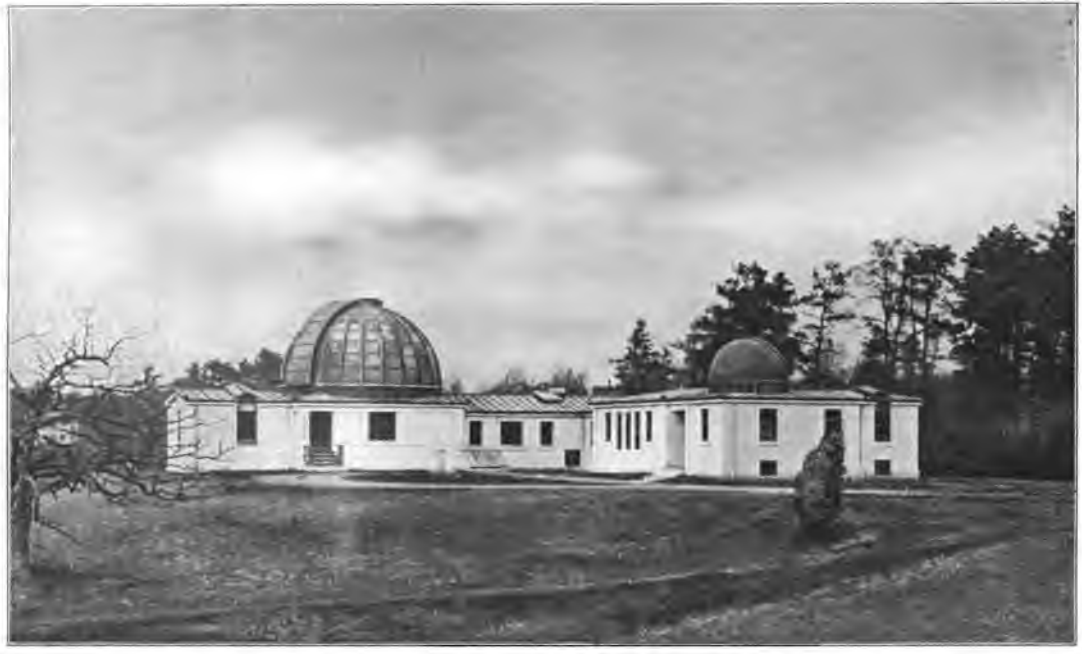

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I. Apparatus for Illustration

Eighteen-inch celestial globe.
Twelve-inch terrestrial globe.
Andrews's tellurion or McVicar's globe.
Gardner's season apparatus.
Columbia planetarium.
Sun-path model.
Willson's miniature equatorial and altazimuth.
Stonyhurst sun disks.
Serviss's star and planet finder.

The apparatus listed above can be obtained through the J. L. Hammett Company, Boston, Massachusetts.

Lemaire field glass, the diameter of the object glasses twenty-four ligne.
Ives's simplex normal spectroscope.
Browning's miniature direct-vision spectroscope. With this small spectroscope all observations may be taken, even to show the coincidence of the *D* line with the sodium line.
Prism spectroscope and accessories for observing the spectra of the lighter metals.
Induction coil and Plücker tubes for showing spark spectra.
Spektraltafel von Kirchhoff und Bunsen, also the colored charts of Huggins and Miller and of Vögel.
Trouvelot's Atlas of Celestial Objects (out of print, but owned by most observatories).
Durchmusterung des Nordlichen Himmels, with the accompanying text.
Uranometria Argentina (charts of the southern sky).

The field glasses, spectroscopes, and charts are furnished by many apparatus dealers, the charts of the northern sky through dealers in

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THE WHITIN OBSERVATORY OF WELLESLEY COLLEGE

Left to right: Bamberg prismatic transit, twelve-inch Clark telescope, concave grating spectroscope, libraries and computing rooms, laboratory with spectrum laboratory below, six-inch Clark telescope, small transit

DAYTIME AND EVENING EXERCISES IN ASTRONOMY

FOR SCHOOLS AND COLLEGES

BY

SARAH FRANCES WHITING, Sc.D.

WHITIN OBSERVATORY, WELLESLEY COLLEGE

UNIV. OF CALIFORNIA

GINN AND COMPANY

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It can be seen then that the ideal equipment for astronomy is an observatory near enough to the centers of

student life to be accessible, equipped with the best instruments. There should be a large laboratory where the students may meet for one of their astronomy exercises in the week, in sections of about fifteen, for the accustomed two consecutive periods of individual work under the direction of a demonstrator. The best books, photographs, charts, and valuable material of the observatory should be brought out for the first-year class. From this class may come the astronomers and the patrons of astronomy of succeeding years.

In general, it is desirable to have the exercises follow as nearly as possible the plan of the lectures and recitations, but orderly arrangement does not seem possible when the objects for consideration are beyond control. Jupiter or Saturn may be visible only in the fall, when students hardly know the difference between a planet and a star; or a comet or "new star" may appear. In these cases students can obtain records of personal observation, and thus have a body of facts to work with when the topic comes up in its proper sequence.

Suggestions for these exercises have come from many sources through a long period. Professor Pickering, director of Harvard Observatory, who opened the first students' laboratory in physics, inspired the writer to attempt students' daytime work in astronomy. General acknowledgment is hereby made for all help, and the hope expressed that these exercises may form a slight contribution to the better teaching of the only science dealing with matter which takes thought off this little planet, and gives those larger conceptions of time and space which stretch the mind and furnish proper perspective for other subjects.

SARAH F. WHITING

WHITIN OBSERVATORY, WELLESLEY COLLEGE

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LIST OF APPARATUS

I. Apparatus for Illustration

Eighteen-inch celestial globe.
Twelve-inch terrestrial globe.
Andrews's tellurion or McVicar's globe.
Gardner's season apparatus.
Columbia planetarium.
Sun-path model.
Willson's miniature equatorial and altazimuth.
Stonyhurst sun disks.
Serviss's star and planet finder.

The apparatus listed above can be obtained through the J. L. Hammett Company, Boston, Massachusetts.

Lemaire field glass, the diameter of the object glasses twenty-four ligne.
Ives's simplex normal spectroscope.
Browning's miniature direct-vision spectroscope. With this small spectroscope all observations may be taken, even to show the coincidence of the *D* line with the sodium line.
Prism spectroscope and accessories for observing the spectra of the lighter metals.
Induction coil and Plücker tubes for showing spark spectra.
Spektraltafel von Kirchhoff und Bunsen, also the colored charts of Huggins and Miller and of Vögel.
Trouvelot's Atlas of Celestial Objects (out of print, but owned by most observatories).
Durchmusterung des Nordlichen Himmels, with the accompanying text.
Uranometria Argentina (charts of the southern sky).

The field glasses, spectroscopes, and charts are furnished by many apparatus dealers, the charts of the northern sky through dealers in

foreign books, the charts of the southern sky through the Cordoba Observatory. Maps of the southern sky in the star atlases can be used if the larger charts are not at hand.

Frame for the illumination of lantern slides.
Screen for projecting sun spots.

These can be made by a carpenter. Sets of lantern slides may often be left for inspection on the support, and changed at intervals. For example, a set showing the complete history of Halley's comet, or famous meteorites, or any other set of pictures which it is desirable to study side by side.

II. Apparatus for Individual Work of Students

Seasonal twilight chart.
Constellation finder.
Six-inch erasable globe.
Hammett's planisphere.

Each student should be supplied with the above apparatus.

Twelve-inch celestial globe.
The solar calculator.

One globe and solar calculator will suffice for each two students.

Colas's map of the moon or the Handy Map of the Moon.

Colas's map of the moon, mounted on cloth, should be tacked to large easels, and one should be provided for each four students.

The American Ephemeris, which can be ordered from the Superintendent of Documents, Washington, D.C.
Viewing-frame for Harvard glass photographs, 8 by 10 inches.
Eyepiece for use with the glass photographs. These can be obtained of the Alvan Clark and Sons Corporation, Cambridgeport, Massachusetts.
Centimeter paper and notebook supplies.
Protractors, compasses, centimeter rulers, paper centimeter scales, etc.

The above apparatus, where not otherwise stated, can be obtained of the J. L. Hammett Company, Boston, Massachusetts. All the apparatus listed is useful and desirable, but selections can be made in beginning a student's laboratory, and additions may be provided from year to year.

LIST OF PHOTOGRAPHS AND GLASS PLATES

Selected regions of the moon: for example, Theophilus–Cyrillus–Katharina; Ptolemy–Alphons–Azachael; Clavius–Tycho; Copernicus; Mare Crisium; Mare Serenitatis; Mare Humorum; Sinus Iridum; the full moon, showing white streaks.

It would be desirable to put into the hands of each student a little booklet of half-tone pictures of different regions of the moon, but this is not yet on the market.

Sun-spot photographs in series, a set for each student.

The Pleiades, with enveloping nebulæ.

Double cluster in Perseus.

Globular cluster in Hercules.

Præsepe in Cancer, as an example of an open cluster.

N. G. C. 2682 in Cancer, as an example of a close cluster.

47 Tucanæ, the region of the Southern Cross, and other photographs of objects in the southern sky.

Messier 5 in Libra.

Two sets of photographs of Messier 5, taken at two different epochs, serve to show the variability of numerous stars in this globular cluster. A pair of these photographs should be provided for each student.

Harvard Map. This is a series of glass chart photographs of the entire sky. The following plates cover the more interesting regions: Numbers 12, 14, 18, 25, 42, 45, 50.

Spectrum plates taken at Harvard Observatory with the objective prism. Interesting plates which contain many types of stars are of the region of the Pleiades, of chi Cygni, of R Cygni, of Wolf-Rayet stars in Cygnus.

Twenty-five selected glass plates of the globular cluster omega Centauri, taken at different epochs. These plates suffice to obtain the light curve of several of the numerous variables in this cluster.

NOTE. The University of Chicago Press sends out a catalogue of photographs taken at Yerkes Observatory. Goodsell Observatory, Northfield, Minnesota, offers a list of celestial photographs. The Georgetown Observatory, Georgetown, D.C., will kindly furnish a limited number of Cestini's drawings of sun spots. The complete Atlas of the Moon, of the Paris Observatory, can be obtained through foreign book dealers. The director of Harvard Observatory shows his practical interest in laboratory astronomy by consenting to furnish plates and photographs at cost as above noted.

DIRECTIONS FOR NOTEBOOKS

1. Reserve three pages for an index, which should be kept up to date, and head successive pages as follows:

Observations with the Telescope.
Naked-eye Observations.
Laboratory Exercises.

2. Head the page of the notebook on which each new exercise is recorded with the date, the proper heading for the exercise, and the student's name.

3. Use unruled paper for drawings, horizontally ruled paper for notes, and checked centimeter paper for graphs. When tables of figures are to be recorded, rule columns vertically in pencil.

4. Make all drawings with sharp pencil; use ink for all else. A fine pen and India ink may be used to advantage in tracing graphs.

5. The notebook should in every case tell briefly and clearly what the student has seen or done; directions should not be copied.

NOTE. The University of Chicago Press sends out a catalogue of photographs taken at Yerkes Observatory. Goodsell Observatory, Northfield, Minnesota, offers a list of celestial photographs. The Georgetown Observatory, Georgetown, D.C., will kindly furnish a limited number of Cestini's drawings of sun spots. The complete Atlas of the Moon, of the Paris Observatory, can be obtained through foreign book dealers. The director of Harvard Observatory shows his practical interest in laboratory astronomy by consenting to furnish plates and photographs at cost as above noted.

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DEC.

Write in the first two columns the following list of stars:

Above 0 Magnitude	
Alpha Canis Majoris	Sir'ius
*Alpha Argus	Canō'pus
0 Magnitude	
*Alpha Ērid'ani	Ar'chenar
Alpha Aurī'gæ	Capel'la
Beta Orionis	Rī'gel
Alpha Canis Minoris	Pro'cyon
Alpha Boö'tis	Arctū'rus
*Alpha Centau'ri	
Alpha Lȳ'ræ	Vē'ga
1st Magnitude	
Alpha Tauri	Aldeb'aran
Alpha Orionis	Bet'elguese (gerz)
Beta Geminorum	Pol'lux
Alpha Leonis	Reg'ulus
*Alpha Crucis	
Alpha Virginis	Spī'ca
*Beta Centauri	
Alpha Scorpii	Antā'res
Alpha Aq'uilæ	Altair'
Alpha Cygni	Den'eb
Alpha Piscis Austrā'lis	Fo'malhaut

Next, with a flexible scale of brass, or better, of paper, measure on the globe the right ascension and declination of each of these stars, and record in the third and fourth columns.

Finally, look up these stars in the "Catalogue of 1520 Bright Stars" from the Harvard Annals, or in the American Ephemeris, or in some catalogue which gives places for 1900.

* The five stars marked with an asterisk are invisible in intermediate northern latitudes.

Remembering that the places on the globe are for the epoch 1850, and that those of the catalogue are for 1900, record in your notebook answers to the following questions:

1. How do the right ascensions as you measure them compare with those from the catalogue?

2. In what two ways might you account for the difference?

3. Which of the two ways is more rational?

NOTE. Hipparchus discovered the precession of the equinoxes in 150 B.C.

EXERCISE II

PROBLEMS TO BE SOLVED BY GLOBES

Object. No chart can give so perfect a representation of the sky as a globe, but the globe has the disadvantage that the observer is looking at the celestial sphere from the outside instead of from the center. Solving a few problems with the globes overcomes this difficulty, and the student finds that a radius of the globe passing through the star on its surface, and extended to the celestial sphere, finds the true star.

Directions. Identify the parts of the celestial globe:

1. The artificial horizon, consisting of the amplitude circle, the azimuth circle, the points of the compass, the signs of the zodiac, the degrees of each sign, the dates of the month.

2. The celestial equator on which the right ascension is reckoned in hours from 1 to 24; the ecliptic on which the signs of the zodiac, each 30°, are marked.

3. The vernal and autumnal equinoxes; summer and winter solstices; zenith and nadir; north, south, east, and west points; the north pole and south pole.

4. The twenty-four hour circles perpendicular to the equator.

5. The brass meridian, passing through the poles of the globe, perpendicular both to the equator and the horizon. By revolving this circle the pole may be set to any elevation, so that the globe may represent the appearance of the heavens at any latitude.

6. A flexible strip graduated in degrees, which may be used to read altitudes.

Problems. 1. Set the globe to show three positions of the sphere with reference to the horizon.

a. The right sphere. Set the poles in the horizon. Note that in this position, which is found perfectly at the equator and approximately anywhere in the tropics, all the stars rise and set each day and move in circles perpendicular to the horizon.

b. The parallel sphere. Set the poles in the zenith and nadir. In this position, which is found perfectly at the poles and approximately within the polar circles, half the stars are above the horizon the whole twenty-four hours, and the other half never rise above the horizon.

c. The oblique sphere. Set the north pole at an elevation above the horizon of 45° and note that the celestial sphere is now divided into three portions: namely, all the stars within 45° of the north pole are above the horizon the whole twenty-four hours; all the stars within 45° of the south pole never rise above the horizon; all the stars of any declination between, rise and set every day.

2. Find the time of sunrise and of sunset, also the length of day at any place at any date.

Elevate the pole a number of degrees equal to the latitude of the place. Find the place of the sun on the given

date by the artificial horizon; that is, find the date and the degree and sign opposite. This is the position of the sun in the ecliptic on the day in question. Find this position on the ecliptic and bring it to the meridian. The globe now represents the appearance of the heavens at noon on the day in question. Now turn the globe until the sun is on the eastern horizon, counting the number of hour circles which pass the meridian. This shows the number of hours between sunrise and noon. Find the time of sunrise, sunset, and the length of daylight at the solstices and equinoxes at the following places: Boston, latitude 42°; London, latitude 52°; the North Cape, latitude 70°. Record the results in columns headed

PLACE	LATITUDE	DATE	SUNRISE	SUNSET	LENGTH OF DAY

3. Represent the appearance of the heavens at any time, for instance, nine o'clock on any date, at a given place.

Set the globe for the place, and find the sun's position on the ecliptic for the date, and place this under the meridian. Turn the globe west, past nine hour circles; then record what constellations are just rising east, setting west, and on the meridian. Thus study the appearance of the heavens at your station at nine o'clock on October 1, January 1, April 1, July 1.

4. Find at what date Sirius will be rising in the east as the sun sets in the west; at what date Sirius will be on the meridian at midnight. Answer the same questions for Arcturus.

EXERCISE III

STUDY OF SEASONS BY GARDNER'S SEASON APPARATUS

NOTE. Demonstrations with the apparatus referred to in this and the following exercise should be given by the instructor. Students should record in their notebooks all observations and answers to questions.

Directions. After a description of the apparatus has been given by the instructor, the globe should be separately revolved to show each point.

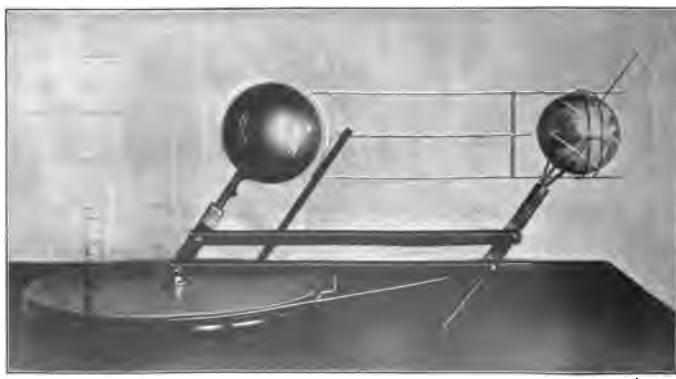


FIG. 1. GARDNER'S SEASON APPARATUS

1. Demonstration of parallelism of axis. Show that in the northern hemisphere in June the axis makes an acute angle with the perpendicular ray from the sun, in September a right angle, in December an obtuse angle, and in March a right angle again.

2. Demonstration of the relation of the circle of illumination to circles of diurnal rotation at the different seasons,

and the consequent length of day and night and amount of heat received.

3. Demonstration of the advance of the oblique ray northward in winter.

4. Demonstration of the tropics and polar circles. The slate globe and chalk may be used for this.

Answer in the notebook the following questions:

1. Towards what point in the sky does the north extremity of the earth's axis point?

2. State the angle which the axis makes with the perpendicular ray from the sun at different times of the year.

3. Define the circle of illumination and state its relation to the circles of diurnal rotation at different times of the year.

4. State when the days and nights are of equal length, and give reasons.

5. State the reason of the long polar daylight and darkness.

6. State the length of the day and of the night at the equator at different seasons.

EXERCISE IV

STUDY OF TWILIGHT BY McVICAR'S GLOBE

NOTE. If the more expensive and elaborate piece of apparatus, the McVicar's globe, is possessed, it can be used for all demonstrations of the parallelism of the axis of the earth and the seasons, but it is especially valuable to show very strikingly the varying duration of twilight from the equator to the pole.

Directions. Set the horizon twilight frame with its zenith over the place it is desired to study (directions accompany

the globe); clamp the frame and revolve the globe. It will be seen that in high latitudes the twilight belt at the summer solstice is traversed nearly all night by the sun.

FIG. 2. MCVICAR'S GLOBE

In the same way show the shortness of twilight at the equator, on account of the perpendicular path across the twilight belt, and the duration of twilight for months at the pole.

It is especially interesting to set the twilight frame for London or Edinburgh, or places in Norway, and to note the reason for the long summer twilights so noticeable to tourists. The very short twilights in places near the equator remarked by tourists to Cuba or Panama may well be demonstrated.

EXERCISE V

STUDIES WITH THE SEASONAL TWILIGHT CHART

NOTE. This exercise consists of two parts, — drawings by the student, and studies by the use of the chart.

Before any work is attempted by the student the instructor should set up a globe and show how the chart is a projection of the celestial sphere on the meridian, from a point of observation due east in the plane of the horizon. The Sun-path Model, set sideways, shows perhaps even better what is meant by the orthographic projection in the plane of the meridian.

Material. Seasonal Twilight Chart, unruled paper, compasses, protractor, also globe and Sun-path Model.

Directions for drawings. 1. On three sheets of paper make circles fifteen centimeters in diameter. Through the center of each draw two diameters at right angles. Use the protractor to make these diameters perpendicular. Mark the horizontal diameter, which represents the horizon projected in a straight line HO; and the vertical one, which is the prime vertical ZN. With the protractor measure on the meridian, below the horizon on each side, an angle of 18°, and draw the small circle which is called "the twilight circle."

2. Complete the figure to represent the conditions in different latitudes as follows:

Measure an angle above the horizon on the north, equal to the latitude of the place, and mark it P. Through it and the center draw PP, the six-o'clock hour circle projected in a straight line.

Measure angles above the horizon on the south, and below on the north, equal to the complement of the latitude, and draw EQ, the equator projected in a straight line. Observe the relation EQ to PP.

Measure on the meridian, both above and below *EQ*, angles equal to the sun's declination at the solstices, namely 23°.5. Draw the diurnal path of the sun at these times. Print in small letters on these diurnal circles the dates when the sun is on them.

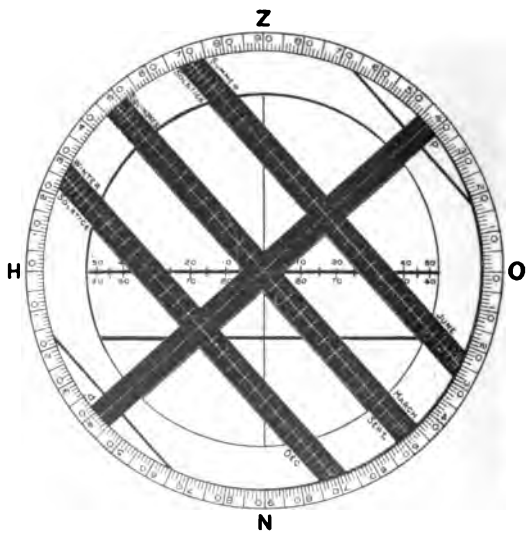


FIG. 3. SEASONAL TWILIGHT CHART

Complete projections for the following latitudes: latitude 72°, the North Cape, within the polar circle; latitude 90°, the pole; the observer's latitude.

Directions for use of chart. With the chart study the following conditions:

1. Latitude 0°, the equator. This will approximately represent conditions at Quito, Singapore, Lake Victoria Nyanza. Note that in these places the north-pole star will be in the horizon.

2. Latitude +23°.5, the northern tropic, near which are situated Havana, Sandwich Islands, Hongkong, Calcutta, Assouan.

3. Latitude 48°.5, nearly the latitude of Paris, Quebec, Vancouver.

4. Latitude 66°.5, the polar circle, near which are Archangel, Iceland, Bering Strait.

Inspect the drawings or the chart and answer the following questions:

1. In latitude 0° how are the twenty-four hours divided?

2. How does the length of day compare with the length of night?

3. How long is twilight at the equinoxes?

4. What is the noon altitude of the sun at the equinoxes? at the summer solstice? at the winter solstice?

5. In latitude 72° what is the length of day at the summer solstice? what is the midnight altitude of the sun? How are the twenty-four hours divided at the equinoxes? at the winter solstice?

6. In latitude 90° discuss the length of day, of twilight, and of night, at the summer and winter solstices and at the equinoxes.

7. What is the sun's altitude in latitude 90° at the summer solstice? How would the sun appear to move that day with reference to the horizon? What would be the form of its path as it gradually sinks to the horizon?

EXERCISES VI, VII, VIII

STUDIES OF THE MOVEMENTS OF MARS, JUPITER, AND SATURN BY MEANS OF GRAPHS

Material. The American Ephemeris, centimeter paper, pencil, centimeter ruler, colored inks, paper centimeter scales or strips cut from the centimeter paper.

Directions for plots. 1. Study the Ephemeris of the planet for the year. Note that the right ascension increases, showing that the planet is moving eastward for some months, but that at a certain date it begins to decrease, showing that the planet has begun to move west or retrograde. Mark on the margin of the Ephemeris the dates of the beginning and end of this retrograde period.

2. Head a page of the notebook "Coördinates of Planet and Ecliptic," and rule five columns.

Date	Jupiter		Ecliptic	
	R.A.	Dec.	R.A.	Dec.

Take from the Ephemeris such coördinates as will place the retrogradation path of the planet in the middle of the sheet. Two dates are enough to take out for each month, except near the turning points.

3. Use a sheet of graph paper lengthwise. Graduate it to a scale in which four centimeters represent twenty minutes of right ascension and five degrees of declination.

4. With a ruler in the left hand to keep the proper right ascension, and a sharp pencil in the right to dot in

the corresponding declination, plot in the points and make through them a smooth fine line with ink. Print in small letters, beside the points, the dates at the beginning of each month.

5. Take out from the Ephemeris the coördinates for the apparent path of the sun (the ecliptic), which corresponds in hours to the path of the planet, and plot it on the graph, using red ink.

6. Take out from the Ephemeris the configurations of the planet for the year in question and record them upon the plot.

7. From the star chart find the most conspicuous stars near the planet, obtain their exact coördinates from a star catalogue, and put them on the graph.

NOTE. These plots should be held above the head toward the south, so that it may be seen that they are a representation of the apparent movements of the planets during opposition. The cause of these movements should be explained.

The above directions are general and will apply to all cases. For convenience, with a large class it is better for the instructor to take out the coördinates to be used and read them to the students, giving directions for the position of the equator on the paper, and for the range of hours in right ascension, and of degrees in declination; also the coördinates of the selected stars.

Inspect the plot just completed and answer the following questions:

1. Is the planet north or south of the ecliptic?

2. Is its latitude increasing or decreasing? Is it approaching an ascending or descending node?

3. How many days did Mars retrograde? Give the date of the middle point of retrogradation. Find the right ascension of Mars on that date, and also of the sun. State the relative positions of Mars and the sun with reference to the earth.

4. What reference stars are most convenient for watching the movements of the planet this year?

5. In what constellation must we look for the planet next year?

Answer the same questions on the graphs of Jupiter and Saturn.

EXERCISE IX

STUDY OF THE MOVEMENTS OF VENUS AS RELATED TO THE SUN — "MORNING AND EVENING STAR"

Directions. 1. Put together lengthwise three sheets of plotting paper.

2. Inspect the coördinates of Venus in the Ephemeris, and note when Venus's retrogradation loop occurs. Take out and tabulate in the notebook such coördinates as will place the loop near the left-hand side of the paper. Make also a list of the coördinates of the sun for the corresponding dates, the first and fifteenth of each month.

3. Graduate the paper to a scale in which each centimeter shall be five degrees of declination and twenty minutes of right ascension. Place the equator in the middle of the paper, and graduate on it the hours of right ascension, also graduate the degrees of declination north and south.

4. Plot in the sun's position, locating each point very distinctly by a red dot, with the date beside it in fine lettering. Connect these positions by a smooth curve in red ink. Similarly plot the path of Venus, marking its positions with black ink dots, the date beside each, and tracing its path in black ink.

5. Cut a narrow strip from the centimeter paper to use as a scale. Write in a table the measured elongation of Venus east or west of the sun for the first and fifteenth of each month.

6. Take out from the Ephemeris the "configurations" of Venus and record them upon the plot.

Questions on the graph. 1. Was Venus east or west of the sun when the plot of its path began?

2. On what date did it pass the sun and become the evening star?

3. In general, on which side of the sun is Venus when it is the evening star? when the morning star?

4. Inspect the table of elongations and state on what date is Venus at the greatest elongation.

5. Find from the table of configurations of the planet when Venus was at superior conjunction, and make a diagram showing in what part of its orbit Venus has been moving ever since.

6. Find from the Ephemeris the date when Venus will be at its greatest brilliancy. Explain.

7. Knowing that Venus shines only by reflected light, what phase does it present at superior conjunction? at inferior conjunction? at the time of greatest brilliancy?

8. Inspect the graph and state the date on which Venus passed ascending and descending node.

9. Measure on the graph the inclination of its orbit to the ecliptic.

10. At what point in its orbit does it retrograde?

The Columbia Planetarium may here be used to advantage. Remove the balls representing the moon and the superior planet, to avoid confusion, and by slowly moving the ball representing the earth show the motions of the

earth and Venus, the positions of inferior and superior conjunction, of morning and evening star.

Put on the ball representing a superior planet, and show the positions of the earth and planet at conjunction, at opposition, etc.

FIG. 4. COLUMBIA PLANETARIUM

EXERCISE X

STUDY OF THE MOON'S MOTIONS DURING A LUNATION

Directions. 1. Take from the Ephemeris the coördinates of the moon at noon each day for the lunation which is chosen. By the proper symbol note on your table of coördinates the time of new, half, and full moon.

2. Put together lengthwise three sheets of plotting paper. As in the Venus plot, graduate to a scale in which each centimeter shall be five degrees of declination and twenty

minutes of right ascension. Place the equator in the middle of the paper and graduate on it the hours of right ascension and also graduate degrees of declination north and south.

3. Plot the sun's path, locating each point very distinctly by a red dot, the first and fifteenth of each month, with the date beside it in fine lettering. Connect these positions by a smooth curve in red ink.

4. Plot in the moon's positions, using each time a small crescent, with its convex side turned toward the sun. Trace the path with black ink, and put in the dates of new, half, and full moon.

5. Using a strip of the paper for a measure of degrees, record in a table the number of degrees traversed each day by the moon. Also in a similar table record the number of degrees traversed by the sun.

Questions. 1. At new moon on which side of the ecliptic was the moon, and what was its latitude?

2. Give the dates at which the moon passed ascending and descending nodes.

3. From this graph show what is the approximate inclination of the moon's orbit to the ecliptic.

4. Inspect the table, giving the number of degrees through which the moon moved each day, and state in what part of the lunation it made the greatest, and also the least, daily progress. What are the names given to the moon's position in its orbit on these dates? Look at the Ephemeris and find the exact dates.

5. Beginning with new moon, on what date did the moon complete a sidereal month, or make a complete circuit in right ascension? How many days in a sidereal month? On what date did the moon complete a synodic

earth and Venus, the positions of inferior and superior conjunction, of morning and evening star.

Put on the ball representing a superior planet, and show the positions of the earth and planet at conjunction, at opposition, etc.

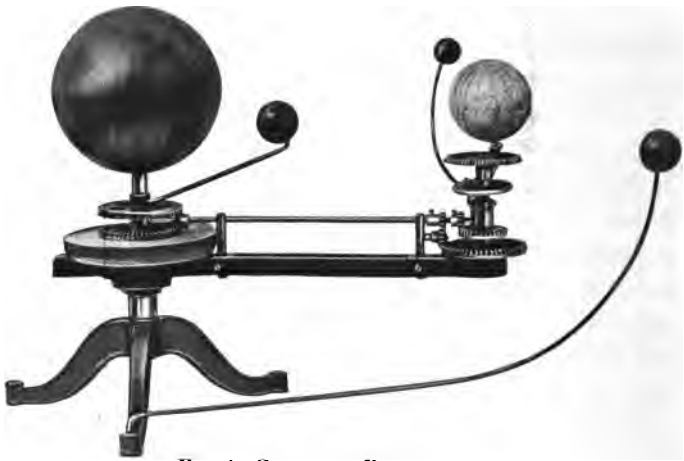


FIG. 4. COLUMBIA PLANETARIUM

EXERCISE X

STUDY OF THE MOON'S MOTIONS DURING A LUNATION

Directions. 1. Take from the Ephemeris the coördinates of the moon at noon each day for the lunation which is chosen. By the proper symbol note on your table of coördinates the time of new, half, and full moon.

2. Put together lengthwise three sheets of plotting paper. As in the Venus plot, graduate to a scale in which each centimeter shall be five degrees of declination and twenty

minutes of right ascension. Place the equator in the middle of the paper and graduate on it the hours of right ascension and also graduate degrees of declination north and south.

3. Plot the sun's path, locating each point very distinctly by a red dot, the first and fifteenth of each month, with the date beside it in fine lettering. Connect these positions by a smooth curve in red ink.

4. Plot in the moon's positions, using each time a small crescent, with its convex side turned toward the sun. Trace the path with black ink, and put in the dates of new, half, and full moon.

5. Using a strip of the paper for a measure of degrees, record in a table the number of degrees traversed each day by the moon. Also in a similar table record the number of degrees traversed by the sun.

Questions. 1. At new moon on which side of the ecliptic was the moon, and what was its latitude?

2. Give the dates at which the moon passed ascending and descending nodes.

3. From this graph show what is the approximate inclination of the moon's orbit to the ecliptic.

4. Inspect the table, giving the number of degrees through which the moon moved each day, and state in what part of the lunation it made the greatest, and also the least, daily progress. What are the names given to the moon's position in its orbit on these dates? Look at the Ephemeris and find the exact dates.

5. Beginning with new moon, on what date did the moon complete a sidereal month, or make a complete circuit in right ascension? How many days in a sidereal month? On what date did the moon complete a synodic

month, or arrive at new moon again? How many days in a synodic month?

6. How many degrees beyond a complete sidereal revolution before new moon? How far then did the sun move in its apparent orbit during this synodic month? Compute the mean distance the sun moves in twenty-nine days, and state how the distance moved this month compares with this mean. Account for this difference. (Is the sun near perihelion or aphelion?)

The Columbia Planetarium may be used to advantage to show the positions of the moon at conjunction, at opposition, etc.

EXERCISE XI

OBSERVATIONS ON THE MOON IN THE SKY

NOTE. These observations must be continued throughout the year, and record made in the notebook to be handed in after each lunation.

Directions. 1. Record the date when you first see the crescent moon in the west. Record also how many degrees north or south from the west point the crescent is seen.

2. Hold up a ruler as a horizontal line, and another ruler or pencil in line with the cusps of the moon. Note the angle which the second ruler makes with the horizontal line. Transfer this angle to the notebook each month.

Fig. 5 shows that the line joining the cusps at the vernal equinox makes an acute angle with the horizon. The figure is made for latitude 42°. Make in the notebook a figure representing the conditions in your latitude; also make a figure representing the conditions at the autumnal equinox.

Use a protractor to make these figures. Show that the old saying, that it is to be a wet or dry month according to the possibility of hanging a pail of water on the crescent, is without meaning, as the position of the crescent for any given month is invariable.

3. Note the position of the moon, with reference to the stars, when first seen, and its position each succeeding

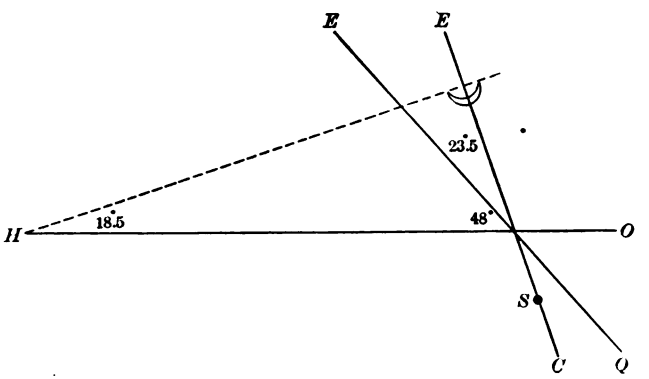


FIG. 5

night. Especially note the dates at which it passes any planets above the horizon. From these observations get a clear idea of the distance through which the moon moves eastward in a day, and of the time it takes for a complete revolution around the earth.

4. Observe during the year the meridian altitude of the full moon, and note that the full moon in winter is where the summer sun is, and that its light is therefore more brilliant than that of the summer full moon.

5. Note the position on the horizon where the full moon rises, that it is always that in which the sun rose six months before.

EXERCISE XII

STUDY OF PHOTOGRAPHS OF THE MOON

Object. To become familiar with the location and characteristics of typical regions on the moon.

Material. Colas's map of the moon (or some other good map), photographs, compasses, ruler, unruled paper.

Directions. 1. Draw a circle with a radius of seventy-five millimeters (this is the largest size convenient on the notebook paper). Draw through the center two diameters at right angles. Mark the top south, the bottom north, the right hand east, the left hand west. The map is to give the appearance of the moon in an inverting telescope. Lay off and mark distances on the horizontal diameter, from the center each way: 73, 70, 64, 57, 48, 37, 25, 12 millimeters. These are the points where the projection of the meridian for each ten degrees cuts the equatorial diameter. Draw meridians through these points and the north and south poles. This can be done fairly well on this small scale by the eye.

2. Sketch in the "seas" from the map, printing the names in small letters.

3. Study each group of photographs displayed. Locate on your skeleton map the most striking features of each region, and record in your notes the results of your study of each photograph: the place at which it was taken, the moon's age, the meridian near the terminator (from the map); whether the moon was waxing or waning; names of the principal mountains from the key; remarks concerning shadows, ridges, white streaks, or peaks which are specially luminous.

For example: Paris photograph. Moon's age, 7.8 days. Terminator, 5° east. Waxing moon. Features: Aristillus, Autolycus, Archimedes, the Apennines, Mare Serenitatis lower left, Mare Vaporum above the Apennines, Manilius left of Mare Vaporum, surrounded by luminous streaks.

4. Finally, make a list of the other photographs of the same region, stating any new features or details observed.

NOTE. Many observatories doubtless possess the superb photographs taken at the Paris Observatory. The most used of these can be backed with cloth and hung on wires about the laboratory for study. The Lick Observatory photographs also are excellent; likewise Ritchie's photographs of selected regions taken at the Yerkes Observatory.

EXERCISE XIII

A STUDY OF THE SUN-SPOT PERIOD BY WOLF'S NUMBERS

Material. A list of Wolf's numbers, loci paper, ruler, and pencil.

Explanation of Wolf's numbers from Monthly Weather Review, November, 1901. In determining the sun-spot activity, Schwabe, its discoverer, counted the spots on the surface of the sun each day, whether isolated or in groups. Wolf, of Zurich, considers the formation of a group of spots more important than the formation of a new spot in a group already existing. He uses the formula $r = 10\,g + t$; that is, the relative number of spots is equal to ten times the number of groups, plus the number of spots. If, for instance, eight spots are arranged in five groups, Wolf's number would be fifty-eight. Wolf's numbers combine the records of different observers reduced to a standard, and begin with 1749.

4. The twenty-four hour circles perpendicular to the equator.

5. The brass meridian, passing through the poles of the globe, perpendicular both to the equator and the horizon. By revolving this circle the pole may be set to any elevation, so that the globe may represent the appearance of the heavens at any latitude.

6. A flexible strip graduated in degrees, which may be used to read altitudes.

Problems. 1. Set the globe to show three positions of the sphere with reference to the horizon.

a. The right sphere. Set the poles in the horizon. Note that in this position, which is found perfectly at the equator and approximately anywhere in the tropics, all the stars rise and set each day and move in circles perpendicular to the horizon.

b. The parallel sphere. Set the poles in the zenith and nadir. In this position, which is found perfectly at the poles and approximately within the polar circles, half the stars are above the horizon the whole twenty-four hours, and the other half never rise above the horizon.

c. The oblique sphere. Set the north pole at an elevation above the horizon of 45° and note that the celestial sphere is now divided into three portions: namely, all the stars within 45° of the north pole are above the horizon the whole twenty-four hours; all the stars within 45° of the south pole never rise above the horizon; all the stars of any declination between, rise and set every day.

2. Find the time of sunrise and of sunset, also the length of day at any place at any date.

Elevate the pole a number of degrees equal to the latitude of the place. Find the place of the sun on the given

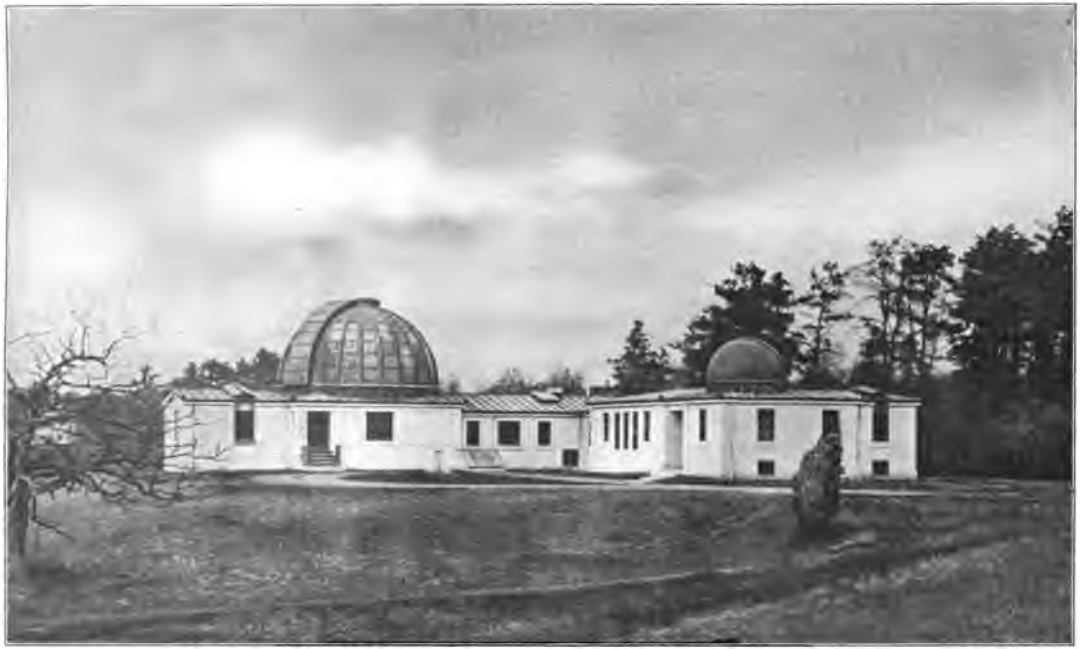
date by the artificial horizon; that is, find the date and the degree and sign opposite. This is the position of the sun in the ecliptic on the day in question. Find this position on the ecliptic and bring it to the meridian. The globe now represents the appearance of the heavens at noon on the day in question. Now turn the globe until the sun is on the eastern horizon, counting the number of hour circles which pass the meridian. This shows the number of hours between sunrise and noon. Find the time of sunrise, sunset, and the length of daylight at the solstices and equinoxes at the following places: Boston, latitude 42°; London, latitude 52°; the North Cape, latitude 70°. Record the results in columns headed

PLACE	LATITUDE	DATE	SUNRISE	SUNSET	LENGTH OF DAY

3. Represent the appearance of the heavens at any time, for instance, nine o'clock on any date, at a given place.

Set the globe for the place, and find the sun's position on the ecliptic for the date, and place this under the meridian. Turn the globe west, past nine hour circles; then record what constellations are just rising east, setting west, and on the meridian. Thus study the appearance of the heavens at your station at nine o'clock on October 1, January 1, April 1, July 1.

4. Find at what date Sirius will be rising in the east as the sun sets in the west; at what date Sirius will be on the meridian at midnight. Answer the same questions for Arcturus.



THE WHITIN OBSERVATORY OF WELLESLEY COLLEGE

Left to right: Bamberg prismatic transit, twelve-inch Clark telescope, concave grating spectroscope, libraries and computing rooms, laboratory with spectrum laboratory below, six-inch Clark telescope, small transit

DAYTIME AND EVENING EXERCISES IN ASTRONOMY

FOR SCHOOLS AND COLLEGES

BY

SARAH FRANCES WHITING, Sc.D.

WHITIN OBSERVATORY, WELLESLEY COLLEGE

UNIV. OF CALIFORNIA

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PREFACE

Astronomy is the last of the sciences to use the laboratory method in teaching its elementary classes. The reason of this is not far to seek. Since no instrument has been invented capable of piercing the clouds, observational work has always been dependent on the caprice of the weather. Photography now furnishes perfect representations of sun, moon, planets, and stars, for daytime study; also many forms of illustrative apparatus can be used by the student to awake and cultivate his imagination and furnish, at first-hand, data for scientific reasoning.

This oldest of the sciences, which has heretofore been a rigid discipline for the few, should now take its place beside the others as a training in the scientific method for the many who pursue the subject chiefly for information and culture.

The management of schools and colleges should make the same allowance of time and money for laboratory instruction in this as in the other sciences; there should be a laboratory, a demonstrator, and fixed hours for students' daytime work. Besides the ordinary instruments of an observatory there should be collections of photographs, charts, and apparatus for the students' own handling.

The only astronomical laboratory books known to the writer are those of the South Kensington School of Science in London, and of Miss Byrd and Professor Robert Willson. These admirable handbooks outline comparatively little

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work which can be done in the daytime, the only time which can be controlled independently of the weather.

The following exercises have been proved to be practical by several years' use with classes of sixty to a hundred, handled in divisions of about fifteen, working two hours a week during the academic year.

In this work the student is, whenever possible, left to draw his own conclusions from data discussed. The American Ephemeris is in constant use, photographs of objects in the sky furnish the "specimens" for inspection, and in this subject, as in botany or zoölogy, "sharpening the pencil sharpens the eyes" — to draw the object fixes the attention upon details of structure. The graph is often used to show the relation between variables, and from it the student can often discover for himself great laws.

Moreover the intelligent person, as well as the professional astronomer, should understand the methods by which, through the daytime study of photographs of the sky taken at night, the great advances in astrophysics have been made. In this subject, as in physics, laboratory exercises can show the methods of research and prepare for it. Most plate work must be left for a second-year course, but a few sample exercises are given. The greatest modern advances in astronomy have been made by the spectroscope, and none of these can be discussed with any degree of comprehension without some laboratory work in spectrum analysis. It would be well if in the high schools simple work with the spectroscope were substituted for some of the less "juicy" experiments now included in the beginning course in physics. As it is, no knowledge of the subject can be counted on, and spectroscopes and their accessories should be provided for work in astronomy.

While this daytime work has high value, it cannot for a moment be advocated to take the place of observation in the open. All is but a means to an end, and the student should never be permitted to bend over chart or plot without fully realizing that it is a strip of the sky overhead that he is considering.

By means of daytime preparation, however, the regular program of evening observations can be greatly helped. With this, a short time out of doors, often under circumstances of more or less uncontrollable discomfort, accomplishes wonders. Directions for the record of observations with the telescope are given, with suggestions for the consultation of the Ephemeris or other publications for accurate descriptions and data.

Every student should, of course, be able to identify the constellations in the sky, and to point out objects which a field glass will reveal. The star names and the mythological figures pictured on the old maps should not be omitted, because of the allusions to them which constantly occur in both modern and classic literature. It is best not to study all the constellations at once, but to prepare for observation as they appear in succession during the academic year.

As one looks at the sky the brighter stars seem to form geometrical figures which catch the eye; within and around these the other stars can be found by alignment. It is worth while to become very familiar with these "catch figures" by sketching them on the star atlas with a pencil in the daytime; they are then quickly recognized in the sky at night. The catch figures used in these exercises are those longest in use; many of them from the old atlas of Burritt.

It can be seen then that the ideal equipment for astronomy is an observatory near enough to the centers of

student life to be accessible, equipped with the best instruments. There should be a large laboratory where the students may meet for one of their astronomy exercises in the week, in sections of about fifteen, for the accustomed two consecutive periods of individual work under the direction of a demonstrator. The best books, photographs, charts, and valuable material of the observatory should be brought out for the first-year class. From this class may come the astronomers and the patrons of astronomy of succeeding years.

In general, it is desirable to have the exercises follow as nearly as possible the plan of the lectures and recitations, but orderly arrangement does not seem possible when the objects for consideration are beyond control. Jupiter or Saturn may be visible only in the fall, when students hardly know the difference between a planet and a star; or a comet or "new star" may appear. In these cases students can obtain records of personal observation, and thus have a body of facts to work with when the topic comes up in its proper sequence.

Suggestions for these exercises have come from many sources through a long period. Professor Pickering, director of Harvard Observatory, who opened the first students' laboratory in physics, inspired the writer to attempt students' daytime work in astronomy. General acknowledgment is hereby made for all help, and the hope expressed that these exercises may form a slight contribution to the better teaching of the only science dealing with matter which takes thought off this little planet, and gives those larger conceptions of time and space which stretch the mind and furnish proper perspective for other subjects.

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